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Pedogenesis of outwash derived soils on terraces of the Des Moines River

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Pedogenesis of outwash derived soils on terraces of the Des Moines River

by

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DEDICATION

I dedicate this thesis to my Lord Jesus Christ whose creation I have strived to understand just a little bit better through this research. I also dedicate this thesis to my loving wife April Dahlhauser who supported me throughout my graduate study and to my son Clyde Harrison Dahlhauser. Finally, I would like to dedicate this thesis to the rest of my family, especially my father Clyde P. Dahlhauser who taught me a love and appreciation for the soil and agriculture.

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NOMENCLATURE

$CaCO_3$	Calcite
$CaMg(CO_3)_2$	Dolomite
DML	Des Moines Lobe
DMR	Des Moines River
HCl	Hydrochloric acid
H_2O_2	Hydrogen peroxide
KCl	Potassium chloride
MAP	Mean annual precipitation
MAT	Mean annual temperature
NRCS	Natural Resources Conservation Service
SMU(s)	Soil map unit(s)
SOC	Soil organic carbon
SOM	Soil organic matter

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ABSTRACT

Soils are a product of parent material, organisms, relief, climate, and time. If all factors except climate could be held relatively constant, the effect that climate plays in the formation of soils could be examined. Following that approach, this study collected and analyzed outwash derived soils from three locations on terraces of the Des Moines River. To provide a climosequence, the three selected locations were spaced out along the length of the river from the NW to SE coinciding with mean annual precipitation (MAP) and mean annual temperature (MAT) both increasing from NW to SE. The soils compared all formed on the same landscape (high river terrace), in the same parent material (outwash), with the same organisms (trees followed by prairie) over the same amount of time (about 11,000 years). Soil profiles were described and soil horizons were analyzed for bulk density, soil texture, pH, soil organic carbon (SOC), inorganic carbon, and mineralogy. The sola sampled are typically loams or clay loams in the upper part of the profiles and gravelly sandy loams in the lower part.

Several trends in the soil properties and morphologies were observed that co-vary with the MAP and MAT climate gradients. The SOC in the upper solum decreases from NW to SE while SOC in lower solum increases from NW to SE. The clay amount and mean particle size of the fine earth fraction are correlated. The southernmost location's sola had fewer coarse fragments, but about 5% more clay in the B horizons. Bulk density increases with depth, but no trend across the three locations was observed. No trend in pH could be determined due to the legacy of land management. Soil survey map accuracy was found to be poor with only seven sola from the 25 sites matching the dominant soil

series in their respective consociations. Depth to carbonate minerals increases approximately 10 cm every 50 km from NNW to SSE. The mass per area of carbonates leached to the depth of effervescence ranges from approximately 1600 Mg/ha in the NW to 5100 Mg/ha in the SE. Data collected and analyzed in this project support the hypothesis that the loamy soil textures observed in the upper solum are primarily due to geological processes such as a waning flow event following a high flow event during the Late Wisconsinan. However, with primary carbonate minerals comprising around 25% of the outwash's mass, leaching of carbonates from the upper solum could also be a significant pedological process that helped alter texture.

CHAPTER 1

INTRODUCTION

Iowa is blessed with rich, productive soils that power the state's agricultural industry. Making up about one-fifth of the state, the Des Moines Lobe (DML) region shown in Figure 1 is noted for its corn and soybean production which in turn supports the livestock sector particularly pork and egg production. This fertile region is a result of the relatively recent glacial deposits of the Late Wisconsinan Stage (approximately 30,000 to 11,000 years before present) and the ensuing pedogenic processes driven by climate and biota that have given rise to the productive soils we observe today.

This study investigated the soils formed in outwash and located on outwash terraces of the Des Moines River (DMR) within or close to the DML. Soil series such as Wadena, Estherville, Cylinder, and Linder are commonly mapped on the highest terraces of the DMR within the DML. The study aims to fill a gap in our knowledge about these soils and to define the transformation of the outwash parent material into soil.

Although outwash derived soils only constitute around 3% of Iowa's land surface (ISPAID, 2016), they are useful to study soil formation due to their coarse nature. In theory, it would be easier to observe transformations and changes in a soil over time if the starting parent material were comprised of predominately large particles. Large particles such as sand and gravel are harder to transport and any increase in the relative proportion of finer particles is easy to determine.

Outwash deposited close to its glacial source is comprised of predominately coarse particles, namely sand and gravel (Ritter et al., 2002). The soils sampled and

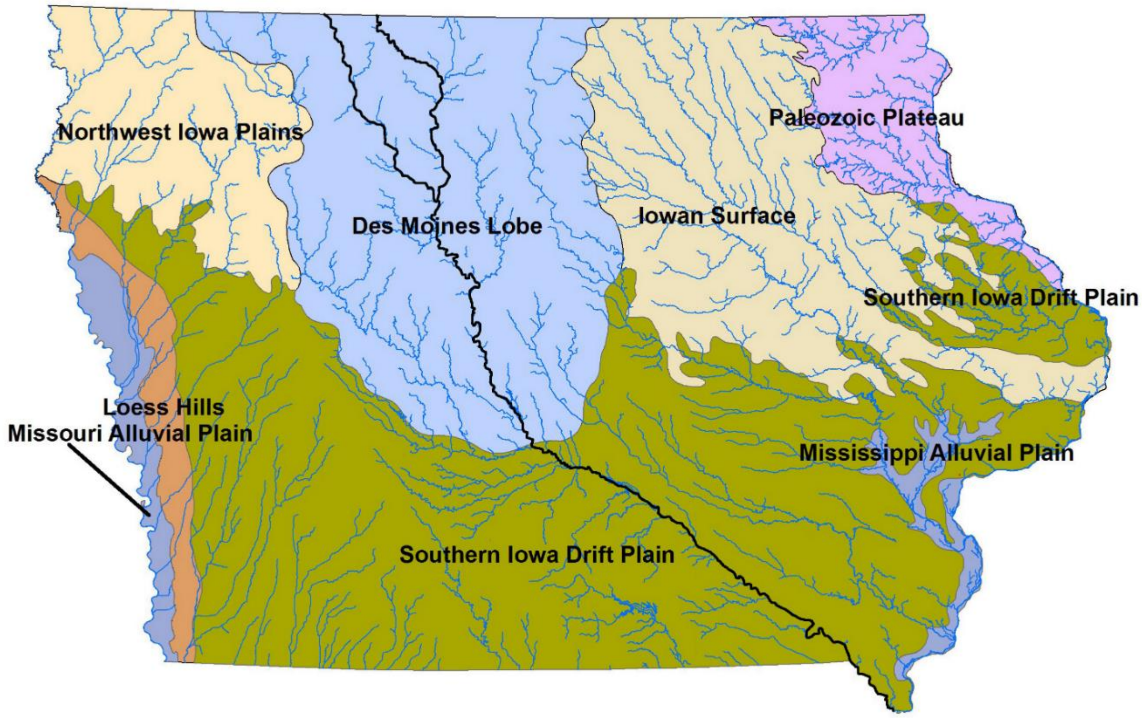

Figure 1. Major landform regions of Iowa and major rivers and streams. Des Moines Lobe is light blue polygon. Des Moines River is black line. Modified from Whittaker (2008), modified from Prior (1991).

investigated in this study are interpreted to have formed in outwash exposed on the land surface. However, NRCS official series descriptions show that the A and B horizons of these soils are generally loams and/or sandy loams with a larger portion of fine particles (silt and clay) than would be found in sandy outwash. Their BC and C horizons are generally composed of sands, gravels, and cobbles as expected of outwash. At the same time, these sola have been leached of carbonate minerals (e.g. calcite and dolomite) to varying depths.

As part of determining profile origins, this investigation also attempts to determine if the upper soil profiles with their finer textures are the result of chemical and physical weathering of the lower outwash sediments or if they reflect a fining upward sequence of sediments due to changes in depositional energy. In other words, is the textural difference pedogenic or geogenic in origin? The null hypothesis is that profile characteristics are primarily inherited from outwash with some influence from carbonate loss and addition of soil organic matter (SOM). The loamy soil textures observed in the surface horizons would be largely due to geological but not pedological processes Loamy surface textures would be due mostly to waning flow events following high flow events during the Late Wisconsinan period as described by Bettis and Hoyer (1986). The alternative hypothesis is that profile characteristics are the product of pedogenesis. Pedological processes such as bioturbation, physical and chemical weathering, and the dissolution of carbonate minerals increasing the clay fraction through the release of impurities would be responsible for generating the finer surface textures overlying the coarser textures.

In this study, soils from three outwash terrace locations adjacent to the DMR were sampled, analyzed, and compared. The soils deemed suitable were all interpreted to have the same parent material, relative relief, biota, and age. However, the three locations vary in climate from near the Iowa-Minnesota border in northwest Iowa (Hallett near Estherville, IA) to farther south and east on the DML (Wildin near Irvington, IA) to the southern tip of the DML in central Iowa (Avon Lake near Carlisle, IA). Figure 2 shows the study locations and Figures 3 through 6 show the soil sampling/coring sites at each location. The properties of these outwash derived soils from the three locations were compared to determine if there are measureable differences in soil development and if any trends that co-vary with climate parameters can be noted.

For example, it has been observed that the depths to effervescence/carbonates appear to increase as you move across the state from northwest to southeast (although there is considerable variability). Another research goal is to determine any trend across the DML for the mass of carbonates leached out of the upper solum.

Outwash and Outwash Terraces

Outwash is a facies often found in glacial depositional environments. Drift is a broad catch-all term for all kinds of sediments deposited in association with a glacier, outwash is unique in its mode of deposition and its particle size composition. In *Process Geomorphology Fourth Edition*, Ritter, Kochel, and Miller (2002) describe outwash thusly:

> *"Sediment deposited beyond the terminal margin of the ice and is formed in the proglacial environment is often referred to as outwash. Outwash is usually well sorted and normally consists of rounded sand and gravel representing bedload carried and deposited in stream channels. Silt and clay are usually carried as suspended load and are commonly removed from the system unless, as in the lower Mississippi River valley, the transport distance is so great that some of the outwash is silty in texture. Streams transporting outwash do not usually head at the glacier terminus but begin on top of, beneath, or within the ice, well upglacier from the margin. Proglacial features and deposits often can be traced into and through the maze of ice-contact deposits, increasing the complexity of the depositional sequence developed near the ice margin."*

(Ritter et al., 2002)

Outwash can be deposited on an outwash plain or within an outwash channel / stream valley. These glacial meltwater streams that deposit outwash are typically braided once they exit the glacial ice and exhibit seasonal flow patterns. During the cold months of winter into early spring there is very little to no flow. However, the warm summer to fall months see the onset of peak flow from abundant meltwater. There are still many present day glacial meltwater-fed braided rivers in the mountainous areas of the northern hemisphere. The McKinley River in Denali National Park, Alaska, is one example.

Outwash streams during the warm months often will have excess sediment load which may lead to net deposition (of primarily sand and gravel) and aggrading of the stream. If at a later time, the source glacier has retreated/melted away, the stream may be able to carry more sediment than is immediately supplied from upstream, so down-cutting will occur causing the outwash deposits to become raised terraces above the current floodplain.

Noah Creek Formation and the Des Moines River

Noah Creek is a tributary of the DMR which is the name given to a geologic formation of the Pleistocene in Iowa comprised of primarily outwash deposits. The Noah Creek Formation has been dated to between 14,000 and 11,000 yr BP by Bettis et al. (1996) using information gathered from Ruhe (1969); Kemmis et al. (1981); Bettis and Hoyer (1986).

According to Bettis and Hoyer (1986), the DMR (both the West and East Fork DMR) originated at the time when the glacial ice was seated at the Algona end moraine (named after the City of Algona) in north-central Iowa circa 12,300 yr BP (Bettis et al., 1996). The West and East Forks of the DMR and the Algona moraine can be seen in Figures 1 and 2 respectively. The modern day valley of the DMR was cut during this time when the englacial streams that would become the West and East Forks emerged from the ice onto the till plain. Figure 7 shows a transverse cross section of the DMR valley and the common stratigraphy that would be encountered in association with the Noah Creek Formation. The various periods of down-cutting yielded the different terraces.

Within the valley of the present day DMR, three different and distinct deposits are commonly observed within the Noah Creek Formation depending on the geomorphic setting. The upper deposit consists of fine-grained to loamy sediments and ranges in thickness from about 0.3 to 1.5 m. The middle deposit consists of cross-bedded sand to pebbly sand to imbricated, matrix-supported cobble gravel. This middle increment typically ranges in thickness from 1 to 2 m. The lower deposit is dominated by cross-bedded sand to pebbly sand to pebble gravel. This portion is typically the thickest ranging from about 2 to 5 m (Bettis et al., 1996).

The lower portion of the formation is interpreted to have been deposited by daily and seasonal fluctuations of meltwater flow from the nearby glacier. The middle portion is starkly different as evidenced by the presence of large cobbles. Its deposition is interpreted to have occurred during one or perhaps two brief but large scale or catastrophic flooding events. This suggestion is based on the fact that there is simultaneous deposition of very poorly sorted, bed-load sized sediments with suspended-load sized sediments. Finally, the upper portion finer sediments that are observed have been interpreted as having been deposited by smaller flood events once the main channels moved a far distance away or had been incised to a lower level. Bettis and Hoyer (1986) suggest that they could be interpreted as overbank deposits. (Bettis et al., 1996; Quade, 1992)

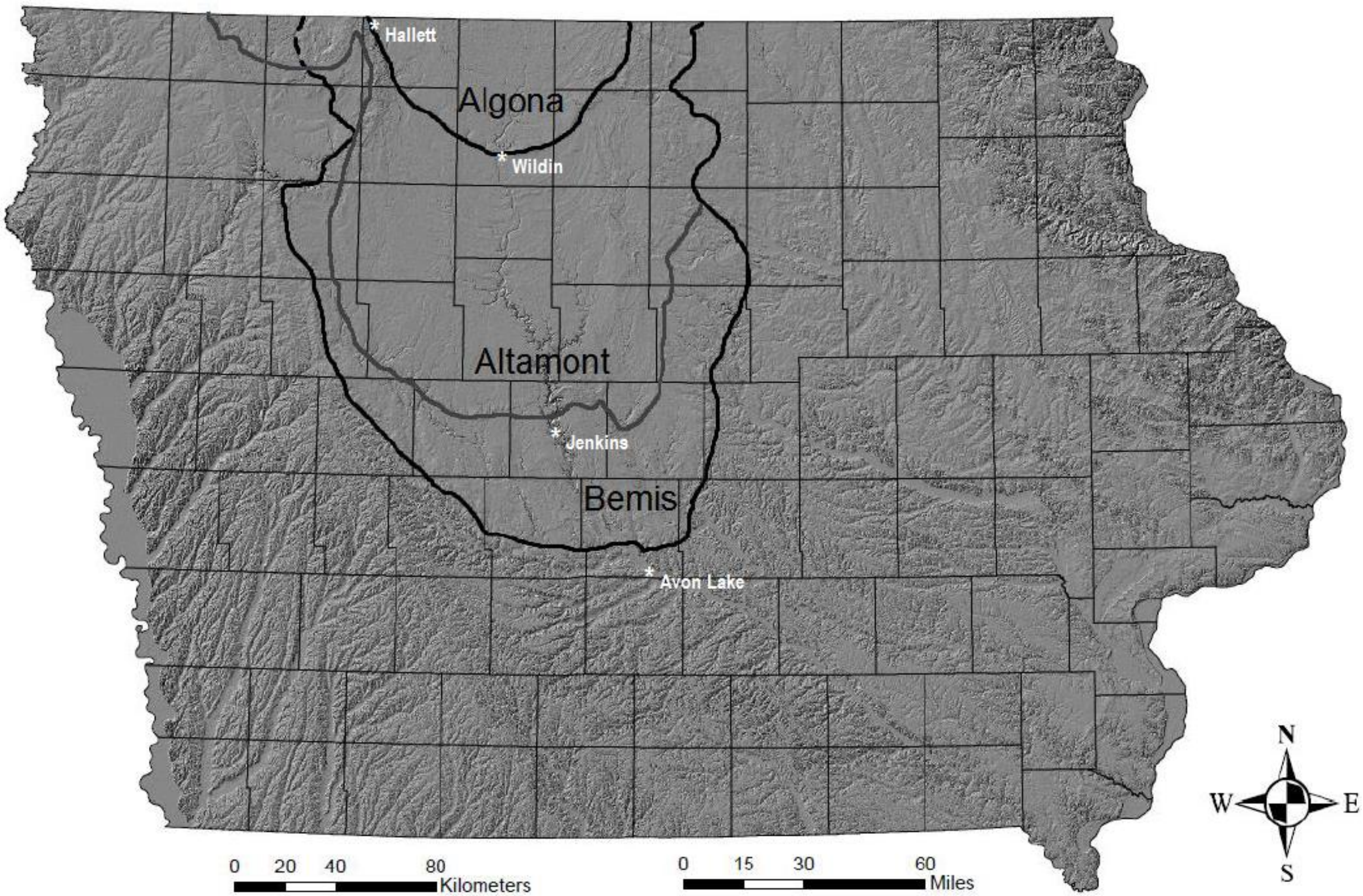

Figure 2. Relief map of Iowa showing the outlines of the major Late Wisconsinan end moraines: Algona, Altamont, and Bemis, and the four study locations: Hallett, Wildin, Jenkins, and Avon Lake denoted by white stars. Data from Iowa Department of Natural Resources GIS Library.

Figure 3. Hallett study location showing coring sites.

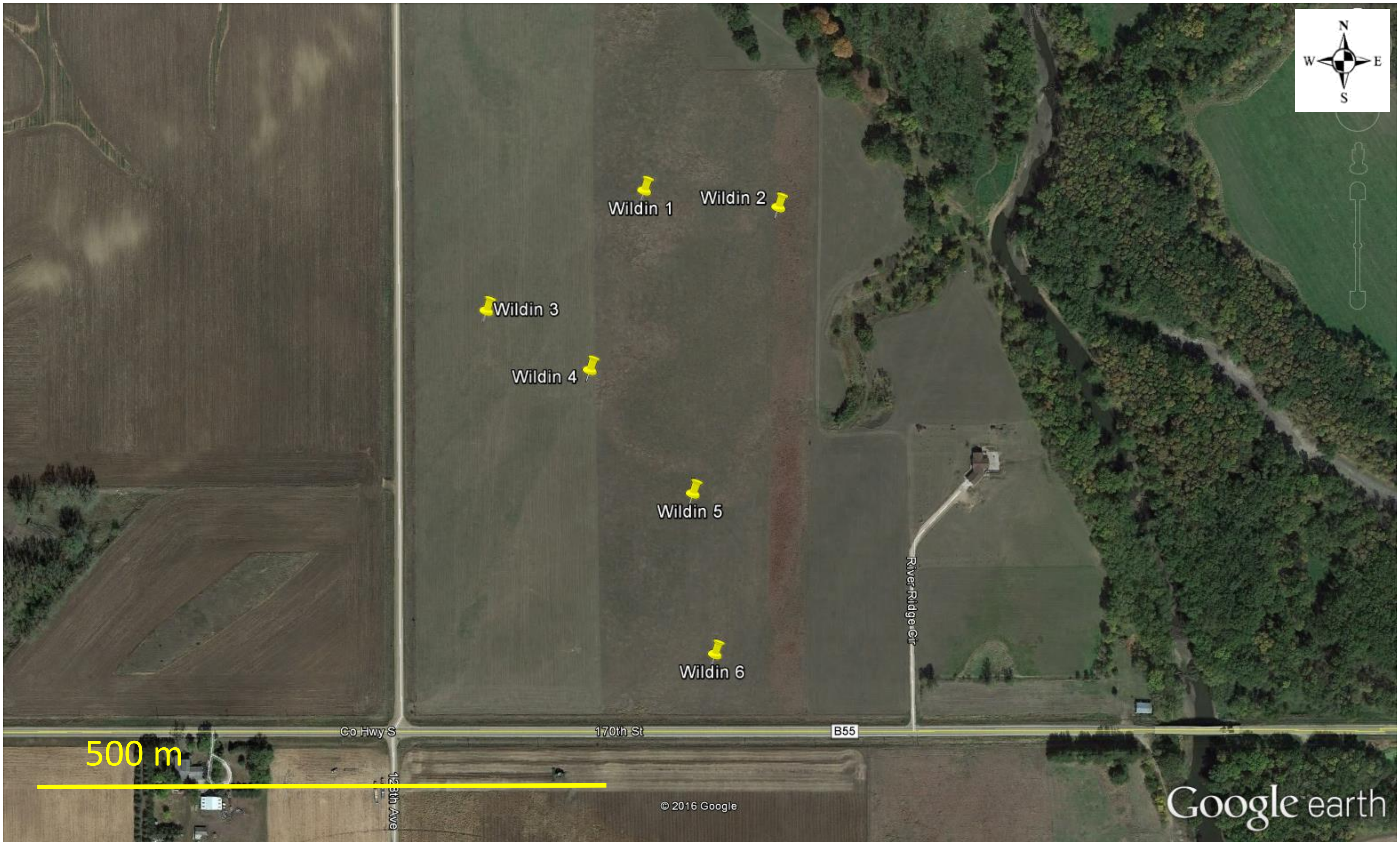

Figure 4. Wildin study location showing coring sites.

Figure 5. Jenkins study location showing coring sites.

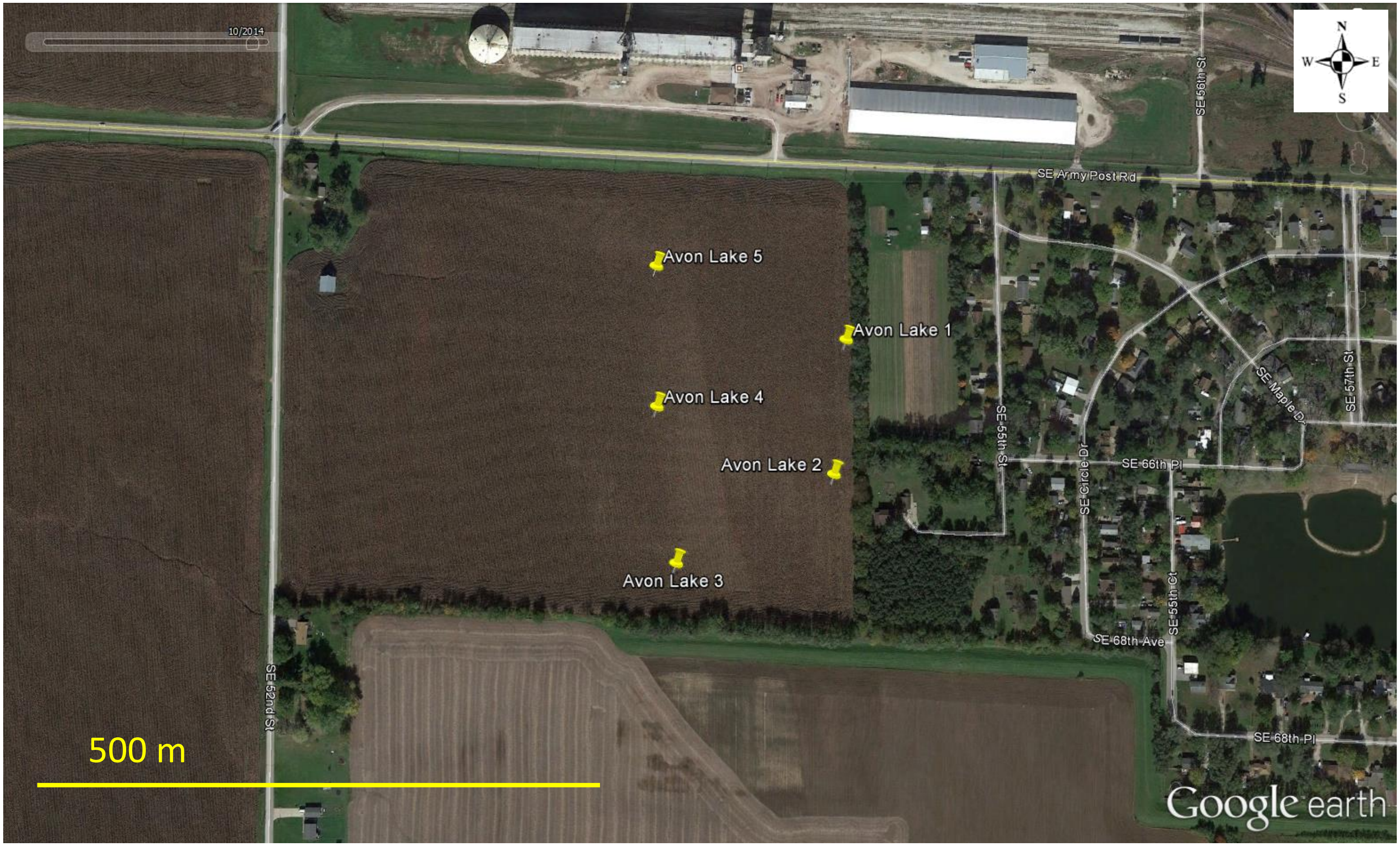

Figure 6. Avon Lake study location showing coring sites.

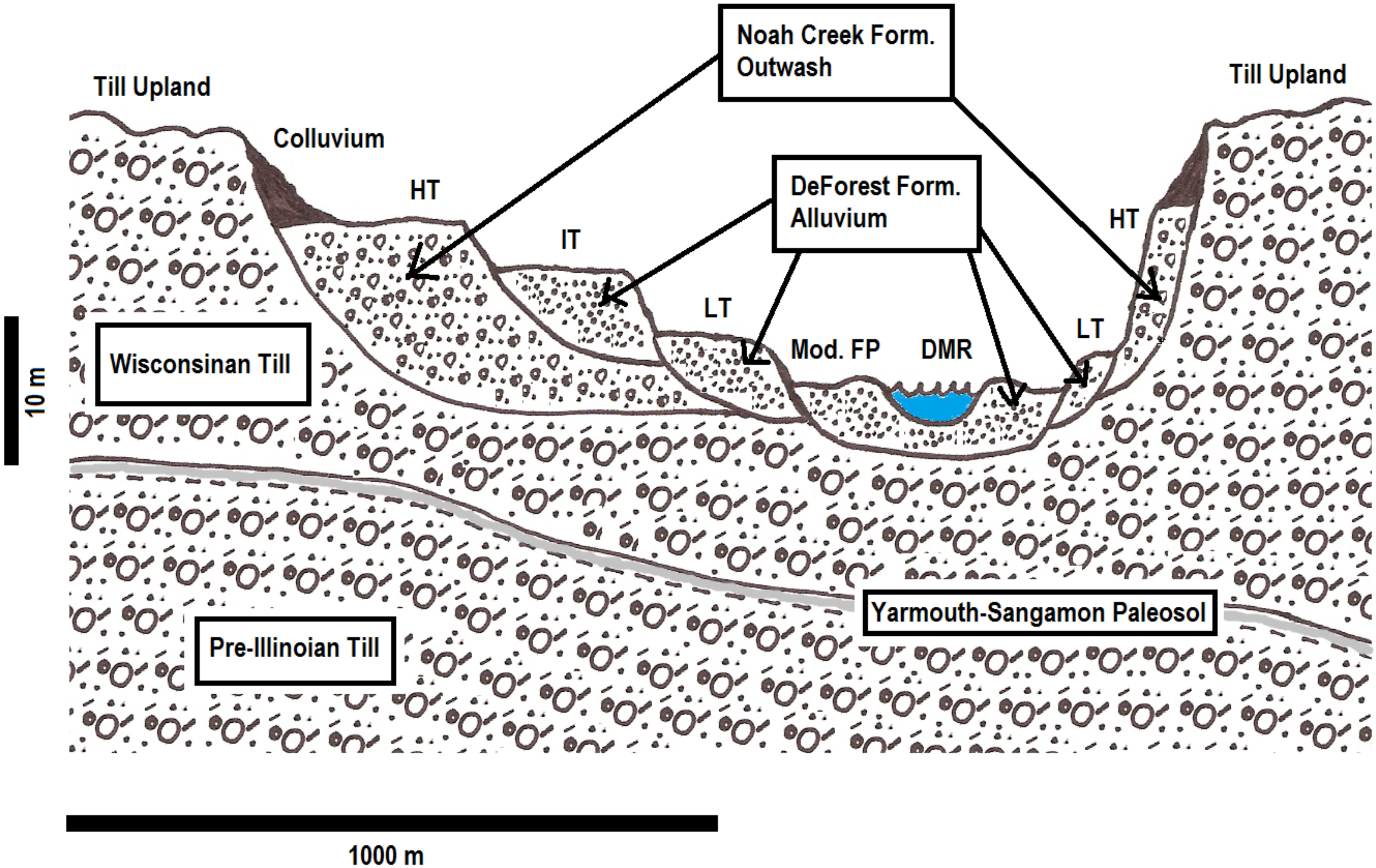

Figure 7. Idealized cross section of the DMR valley stratigraphy within the DML. [“HT” – High terrace, “IT” – Intermediate terrace, “LT” – Low terrace, “Mod. FP” – Modern day floodplain, “DMR” – Des Moines River]

The lithology of the outwash is variable and is controlled largely by the source zone of the ice flow. It seems reasonable to suggest that the lithology of the outwash sediments of the Noah Creek Formation is similar to the lithology of the coarse fraction of the adjacent tills (diamicton). A gravel sample collected in this study from an outwash terrace of the West Fork of the Des Moines River north of Estherville, Iowa, had various rock types represented including, but not limited to, sandstone, limestone, quartzite, and granite. In a publication by the U.S. Geological Survey (1958), outwash from Tazewell drift deposits was examined, and a rock count of the pebble fraction was conducted. Data from their findings are listed in Table 1.

Table 1. Abundance of rock type in pebble samples from outwash from Tazewell drift from U.S. Geological Survey (1958)

Rock Type	Abundance
Limestone	33%
Granite	28%
Concretions, Iron Oxide, from Pierre Shale	17%
Quartz	14%
Gabbro and Basalt	10%
Chert and Chalcedony	2%
Pierre Shale	1%

Pedogenesis of Sampled Outwash Derived Soils

This study described numerous soil profiles across the three previously mentioned locations (an additional fourth location was deemed unsuitable for comparison). As will be mentioned again later, most of the described soils did not match up with the appropriate soil map unit (SMU) as described on the soil survey reports. Soil series described and identified as forming wholly or predominantly in outwash across the three locations were the Wadena, Estherville, Cylinder, Fort Dodge, Spillville, Warsaw, Dakota, and Wiota series. The first five listed are taxonomically classified as Hapludolls, and the latter three are Argiudolls.

While each soil series is unique for a variety of reasons, the following subsections make an effort to summarize the general story of pedogenesis for the outwash derived soils at the three locations that were identified as the aforementioned soil series. The lack of some small details and exceptions are acknowledged.

As stated previously, the soils sampled on the outwash terraces of the DMR were formed in deposits of the Noah Creek Formation. The deposits associated with the DMR are narrowly constrained in age since the DMR was not cut into the landscape until circa 12,300 yr BP. Following the scouring of the DMR into the till plain, the outwash was deposited in the aggrading river until the ice retreated around 11,000 yr BP (Bettis et al., 1996).

Models of soil formation

The Jenny (1941) model of soil formation, as well as the Simonson (1959) model, can be used to explain the development of these soils. According to the Jenny model, soil forms as a result of five independent factors: parent material, biota, climate, relief, and time. This model can be expressed by the following function:

$$S = \int (pm, b, c, r, t)$$

(Schaetzl and Anderson, 2005)

Simonson looked at soils from a perspective of gains, losses, translocations, and transformations. For example, the initial sediment present that will become a soil will experience a gain in organic matter, a loss of calcium carbonate (if present) through dissolution and leaching, translocation of clays from an upper horizon to a lower horizon, and a transformation of some primary minerals into secondary minerals. This can be expressed as the function:

$$s = \int (g, l, tl, tf)$$

(Schaetzl and Anderson, 2005)

Biota

These soils formed predominately under tall grass prairie particularly for the past 8000 years (Prior, 1991). However, it is likely that after initial colonization of the outwash sediments by lichens and mosses, a long succession of plant species occurred. Viereck (1966) gives an excellent description of plant succession on a chronosequence of five adjacent outwash terraces in Denali National Park, Alaska. Given that the climate of southern Minnesota and northern Iowa circa 11,000 years ago was more similar to that of the Alaskan climate at present day, it seems reasonable to suggest that the early soils forming on outwash in Iowa would have exhibited a plant succession similar to that described by Viereck (1966). This succession is described in Table 2.

Following the rapid retreat of the glacier, the southern Minnesota and northern Iowa climate warmed up quickly enough that plant succession would not have approached the fifth stage described by Viereck (1966). However, temperatures remained cool enough as the glacier was retreating, and even up to about one thousand years after it retreated, that coniferous forests emerged. Several varieties of conifers such as spruce, larch, pine, fir, hemlock, and yew are known to have grown in abundance in the area and

Table 2. Terrace ages and the stages of plant succession found on each terrace. Based on Viereck (1966).

Terrace	Age (yr)	Stage Components
I	25 to 30	Pioneer Stage: Mat and clump species, only a few centimeters high, some pockets of lichens, several species of legumes present, 50% vegetative cover,
II	100	Meadow Stage: Grass meadow, small pockets of willow and other shrubs, some herbaceous plants, under the grasses is a nearly continuous moss mat, 99% vegetative cover
III	150 to 200	Early Shrub Stage: Thick moss mat underlying a mat of low shrub birch (1 to 1.5 m high), some willows, some herbs, few grasses, 100% vegetative cover
IV	200 to 300	Late Shrub Stage: Dominated by low shrub birch with it covering nearly 90% of the area, underlain by a continuous moss mat thicker than Stage III (20 to 30 cm thick) with some tundra moss species present, 100% vegetative cover
V	5,000 to 9,000	Low Shrub-Sedge, Tussock-Moss Tundra: 25% is tussocks of a sedge called *Eriophorum vaginatum* that prefers acidic environments, low shrub birch grows to about 25 cm, the underlying moss mat has morphed into a hummocky surface with 20 to 30 cm relief, occasional shrubby white spruce, 100% vegetative cover

on the Noah Creek Formation (Anderson, 1983; Bettis et al., 1996). Conifers dominated the land surface up until about 10,500 yr BP, when the climate began to warm up and the conifers gave way to deciduous forest species such as box elder, walnut, willow, elm, oak, and hickory. Around 9,000 yr BP, the climate began to dry up in Iowa, and tall grass prairie started to move in. By 8,000 yr BP, prairie had virtually replaced all deciduous forests except for those located right along some bodies of water. Probably starting around 3,000 yr BP and continuing to the present, the climate moistened and deciduous forest started to expand where the conditions allowed. (Anderson, 1983)

Although, undoubtedly, many varieties of plants have grown on the soil and helped in its early formation, the dominant plant life on the soil surface for the past 8,000 years has consisted of tall grass prairie species such as big bluestem, little bluestem, blue grama, foxtail, and canary grass, as well as many species of herbaceous plants. Today, most of the sampled soils and similar outwash soils are planted to corn and soybeans.

Climate, relief, and time

Mean annual precipitation (MAP) varies from 780 mm at the northernmost location near Estherville, IA, to 915 mm at the southern location near Des Moines, Iowa. Figure 8 shows the MAP distribution across the state. Mean annual temperature (MAT) also varies from north to south. MAT in the north is about 8.9˚C whereas in the south, it is about 11.0˚C. (U.S. Climate Data, 2016). The climate of the northern half of Iowa has largely been the same for the previous 3,000 years. However, from about 8,000 yr BP to about 3,000 yr BP, the climate is believed to have been a little drier. This drier period may account for why the deciduous forests declined and tall grass prairie predominated (Anderson, 1983). The biota of the area is largely controlled by the climate.

Very little relief is present on outwash terraces. For example, the sampled soils have slopes of 0% to 5%. Typically the slope was 1% to 2%. The slopes varied from planar, slightly convex, to slightly concave.

These soils likely formed over approximately the last 11,000 years. Soil formation would have begun once the stream down-cut leaving an outwash terrace no longer subject to medium-high flow during flood events. Walker (1966) discusses how there was a couple of alternating periods of stable and unstable landscapes subject to erosion and deposition of sediments during the DML's history. If that were the case for these terraces, then the starting time of formation for the present day soils may be harder to pinpoint. However, these terraces are very flat and therefore unlikely to have experienced drastic erosion events.

Gains, losses, translocations, and transformations

This sub-section gives a brief overview of gains, losses, translocations, and transformations according to Simonson's (1959) model that have occurred during the formation of the sampled soils. As stated previously, the parent material in which the sola formed was glacial outwash. At the time of deposition, the parent material would have contained virtually only inorganic materials, primarily rocks, lithic fragments, and minerals. This means that there would have been essentially zero nitrogen and zero organic carbon. However, with colonization of lichens and eventually plants on the outwash materials, organic matter was added to the soil, primarily in the upper horizons. This organic matter contains carbon and nitrogen that is then stored in the soil. As the soil aged under different plant successions, carbon and nitrogen levels increased probably similar to data from Viereck (1966) shown in Table 3 (excluding Stand V: Climax Tundra). Under tall grass prairie, organic carbon and nitrogen levels would have

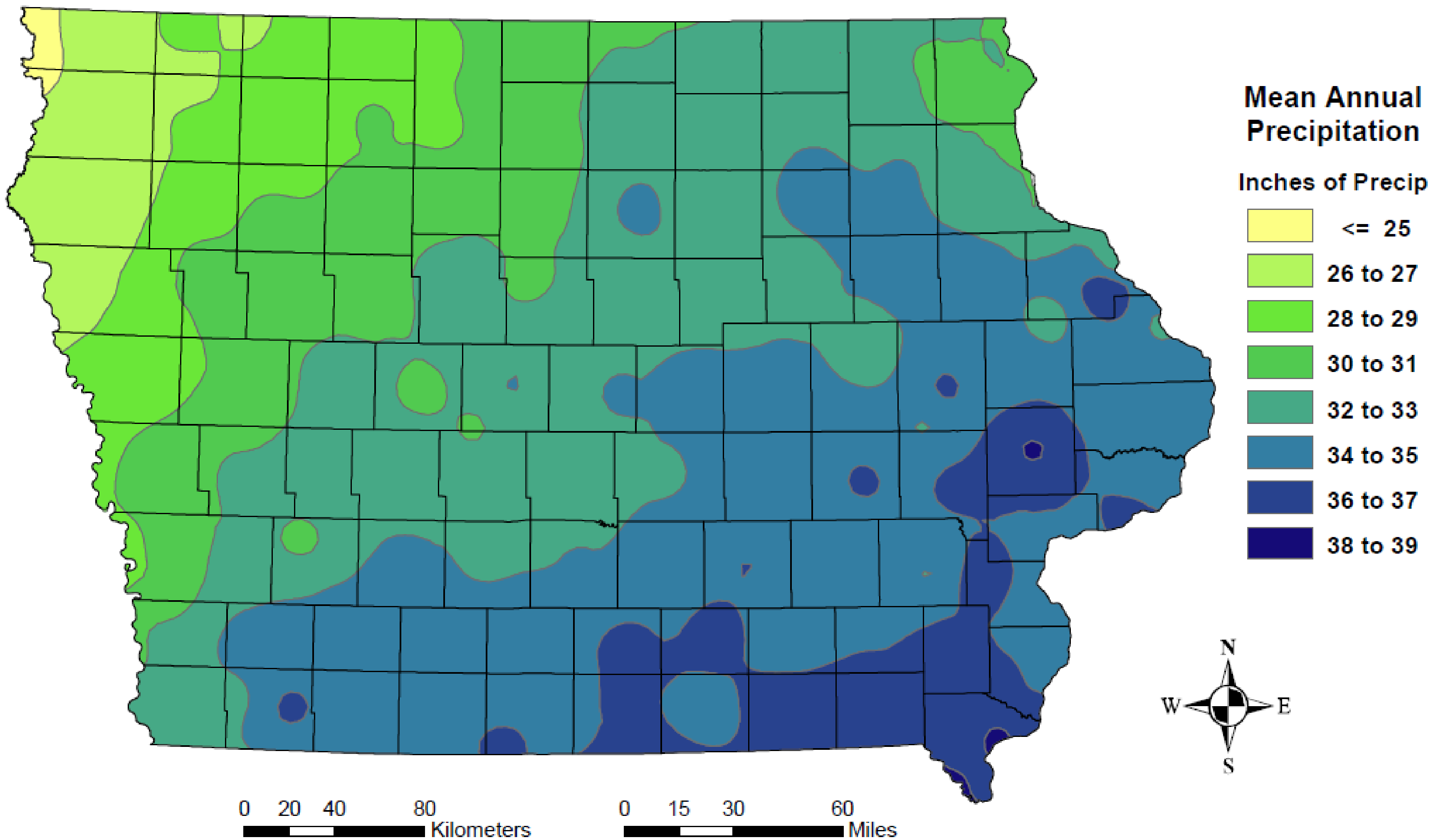

Figure 8. Mean annual precipitation across Iowa. Data from Iowa Department of Natural Resources GIS Library.

increased until the advent of agricultural degradation of the soils beginning about 160 years ago.

Several losses have occurred in varying degrees over the course of the development of these soils. Some erosion of soil particles may have occurred, but the amount of erosion is likely limited due to gentle slopes (usually 1-2%), good drainage, and good vegetative cover. This soil erosion would have removed some organic carbon, nitrogen, phosphorus, and mineral particles. There has also been a loss of carbonates from these soils. Carbonate minerals in upper horizons of the soils began to dissolve due to carbonic and organic acids. Much of the dissolved load would have reprecipitated in the lower horizons or laterally through the horizons across the landscape, but some would have been carried completely out of the soil system with the groundwater.

Some translocations have occurred in these soils. With a decreased pH in the A horizons, some clays were able to move to lower horizons to create cambic B horizons (or in the case of a few sampled soils, argillic horizons). These B horizons show a color change from the overlying A horizons and a slight (to significant) increase in clay content (Soil Survey Staff, 2016). Also, as mentioned before, some of the carbonates dissolved in the upper horizons reprecipitated in the lower horizons. This reprecipitation typically occurs when the dissolved load reaches a horizon with a basic pH.

Several transformations have taken place in the sampled soils as well. A portion of the phyllosilicate clays (e.g. muscovite, illite, vermiculite, etc.) has been chemically weathered and broken down releasing nutrients for plant uptake. The released nutrients were then stored as organic matter in the soil. PH has also decreased to below 7 in the A and B horizons. Due to physical and chemical weathering, some of the sediment particles have been broken into smaller particles. This usually led to an increase in the silt fraction and a decrease in the sand fraction. Viereck (1966) observed this trend in outwash soils in Alaska. This trend is shown in Table 3.

Table 3. Soil characteristics at different depths in outwash terrace soils of different ages and stages of plant succession. From Viereck (1966).

Soil depth	Soil characteristics	I Pioneer stage	II Meadow stage	III Early shrub stage	IV Late shrub stage	V Climax tundra
5 cm	Sand	78.0	88.3	82.0	70.7	—
	Silt	17.8	11.5	15.5	21.7	—
	Clay	4.2	1.3	2.5	7.7	—
	Organic	4.42	16.7	18.7	7.66	—
	Nitrogen	0.0264	0.1285	0.1605	0.1708	—
	pH.	7.7	6.0	5.7	5.4	5.0
10 cm	Sand	86.4	85.0	80.0	69.7	74
	Silt	10.4	14.7	17.2	25.0	22
	Clay	3.2	3.0	2.2	5.3	4
	Organic	4.36	4.7	4.7	5.0	31.6
	Nitrogen	0.0132	0.0794	0.1193	0.1004	—
	pH.	8.0	6.7	6.7	6.5	—
20 cm	Sand	91.2	90.7	86.2	80.8	71
(15 cm for	Silt	5.6	7.5	11.5	16.0	26
Stand I)	Clay	3.2	1.8	2.2	3.3	3
	Organic	3.76	3.6	3.6	4.4	54.9
	Nitrogen	0.0125	0.0333	0.0376	0.0444	—
	pH.	8.0	7.3	7.2	7.4	5.2
30 cm	Sand	—	93.8	90.7	87.0	74
(40 cm for	Silt	—	4.4	6.0	9.3	22
Stand II)	Clay	—	1.8	3.0	3.7	4
	Organic	—	4.2	4.5	—	25.9
	pH.	—	7.7	7.5	7.8	5.3
50 cm	Sand	—	—	94.0	86.0	—
	Silt	—	—	3.5	10.0	—
	Clay	—	—	2.5	4.0	—
	Organic	—	—	4.5	4.0	—
	pH.	—	—	8.0	7.8	—

Example Soil

Given the youthfulness of the soils, the presence of calcareous minerals, and the predominance of prairie vegetation, these soils are not as well developed as some other soils in the State of Iowa. This is evidenced by the predominance of cambic B horizons. One typical example of an outwash derived soil in Iowa is the Wadena series. Wadena soils are fine-loamy over sandy or sandy-skeletal, mixed, superactive, mesic Typic Hapludolls. They are well drained. They have moderate permeability in the solum and very rapid permeability in the underlying coarser sediments. According to the official series description of the Wadena series published by the Natural Resources Conservation Service (NRCS), the geographic setting of these soils are as follows:

> *"These soils have plane, slightly convex, and concave slopes on nearly level to rolling outwash plains and valley trains. Slope gradients range from 0 to 18 percent. They formed in glacial outwash sediments consisting of a 24 to 40 inch loamy mantle over sandy and sandy-skeletal sediments. These sediments are Late Wisconsin age. The climate is continental with warm summers and cold winters. Mean annual temperature is 45 to 55 degrees F. Mean annual precipitation is 25 to 36 inches. Frost-free days range from 124 to 190. The elevation above sea level ranges from 700 to 1600 feet."*

(Soil Survey Staff, 2014)

The future development and transformation of these soils will be interesting to observe as the long term effects of intense agricultural use start to manifest themselves. A minor threat to the future of these soils is sand and gravel quarrying. These soils are frequently stripped off the surface to excavate the underlying sands and gravels. Quarrying companies are always actively searching for new sand and gravel bodies to exploit.

CHAPTER 2

MATERIALS AND METHODS

Study Areas

Selection of the study areas was essential to this project. Being that this study focuses on investigating soils within a climosequence, it was necessary to have multiple study areas which vary in climate while holding all other factors constant. Four locations on outwash terraces along the extent of the DMR from northwest to southeast Iowa were selected along a progression of MAP and MAT. The final selection of research locations centered on three fundamental criteria: appropriate age and landform based on surficial geology maps (Quade et al., 2001, Quade et al., 2002, Quade et al., 2003, Quade et al., 2004), outwash derived soil series mapped by NRCS (Web Soil Survey, 2016), and ground truthing to assess suitability.

Because this project intended to evaluate depth and intensity of physical and chemical weathering through a climosequence approach, the age of the parent material (time of deposition of outwash sediments) needed to be constrained. One way to control for the age of deposition of the outwash is to select sites on a continuous terrace. However, due to the nature of river dynamics, the DMR has meandered over the previous 10,000 years and truncated the continuity of the terraces. Fortunately, much work has been done to correlate the terraces based on their geomorphology and sedimentology. Based on Bettis and Hoyer (1986) and Iowa Geological Survey surficial geology maps (Quade et al., 2001, Quade et al., 2002, Quade et al., 2003, Quade et al., 2004), the places for investigation were located on the highest outwash terraces present in the northern reaches of the river. Localities in the south were to be on “Intermediate to High” terraces. The assumption was made that the time of deposition, relief, and Holocene biota at each location is the same. Google Earth, LiDAR data (Iowa Geographic Server, 2016), and NRCS soil survey reports (Web Soil Survey, 2016) were then utilized to pinpoint ideal locations on the targeted terraces for further examination.

To clarify terminology, from here on the term “location” refers to one of the four study locations consisting of multiple hectares, and the term “site” refers to a specific coring site (i.e. point) at a given study location.

Any site that passed the initial criteria (mapped as high terrace comprised of outwash, suitable topography, easy access, and mapped soil units formed from outwash) was then visited for ground truthing after obtaining the permission of the respective landowners/managers. A determination was then made as to whether or not a location would be suitable for the purposes of the study. Four locations were deemed suitable to investigate. These are referred to in this paper as Hallett, Wildin, Jenkins, and Avon Lake (Figure 2).

After the collection, description, and lab analysis of the soil samples, it was determined whether or not the location or sites within a location truly contained outwash derived soils. An outwash deposit close to its glacial source should contain somewhat rounded, moderately well sorted sediments ranging in size up to at least coarse sand (Ritter et al., 2002). A lack of coarse sand may suggest alluvium and not outwash.

Soil Core Collection

Before field collection of the soil cores, a strategy for collection was devised. LiDAR data and county soil survey reports were consulted once again to pick specific sampling sites at each of the four locations. For comparability, coring sites were selected to capture the variability in topography across a terrace and the variety of SMUs. Terraces by nature are typically flat, gently sloping planes. However, due to depositional processes and landscape evolution, relief across a terrace is present. As such, coring sites were selected on localized summits, shoulders, backslopes, and footslopes. Each location had five to eight coring sites with two cores to be collected at each site. Twenty-five coring sites in total were used in this study (Figures 3 through 6).

Figure 9. Author collecting soil cores using Giddings soil probe.

UTM coordinates were recorded at each coring site using Google Earth (Appendix D). This allowed for easy navigation to specific locations in the field with the use of a handheld GPS device. Other core attributes recorded included sampling depth, slope, landscape position, and field conditions (e.g. vegetative cover, presence of stones on the surface).

Soil cores were collected using a pickup-mounted hydraulic Giddings Probe (Figure 9). This machine is capable of pushing a steel tube deep into the soil. The tube used (Figure 10) had a diameter 6.3 centimeters and a length of 152 centimeters. Upon raising the probe out of the ground, the soil core would then be extracted and stored in a length of PVC pipe (cut lengthwise in half), wrapped in plastic sheeting, and secured with plastic zip ties (Figure 11). With duplicate cores collected at each predetermined site, one core was to be examined and the other was to be held in reserve as a backup and to create mineral thin sections.

Soil Profile Description

Profile descriptions are foundational to pedology and as such serve as the starting point for this study. Pedological information was recorded for each soil horizon following Schoeneberger et al. (2012). This included depth of horizon, boundary condition, moist soil color, estimate of texture class, estimate of clay percentage by feel, proportion of coarse fragments (> 2 mm), structure, moist consistence, presence of coatings, (e.g. clay), size and amount of roots, size and amount of pores, presence of calcium carbonate minerals, description of redoximorphic features, and description of any other anomalous properties. Resulting profile descriptions may be viewed in the results and discussion chapter.

Figure 10. Steel Giddings probe tube

Bulk Density Determination

Bulk density is defined as the dry mass of a soil divided by the volume occupied by solids and pores in a soil (Manu & Schafer, 2013). Given that the core of soil collected is cylindrical, volume was calculated by using the length of a soil partition (*l*) and the radius of the probe tube's tip (3.15cm). Bulk densities were to be measured for every soil horizon, so the thickness of the horizon served as the length of the soil partition. The simple equation of Volume = π*radius^2*l gives the bulk volume of a soil horizon.

$$\text{bulk density} = \frac{\text{oven-dry mass of soil}}{\text{bulk volume of soil}}$$

Equation 1.

Each horizon was assigned a labeled metal tin (or tins if large enough). The empty tin was weighed on a two-decimal-place balance and weight recorded. All soil from the previously measured and described soil horizon was then placed in the tin. The soil and tin were then placed in a drying oven to dry for a minimum of 24 hours at a temperature of 105˚C. After the soil was oven dried, it was removed from the oven and quickly transferred to the two-decimal-place balance to measure and record the weight of the soil plus tin. After

Figure 11. Securing soil core in plastic sheeting.

subtracting the weight of the empty tin from the aforementioned weight, oven dry weight of the whole soil horizon was known.

$$\text{bulk density} = \frac{\text{dry mass of soil and tin - mass of tin}}{\pi\,(\text{radius of core})^2 * \text{depth of horizon}}$$

Equation 2.

Bulk densities were calculated for all horizons and whole cores using the above equation with dry mass of soil and tin and mass of tin in units of grams, radius of core and depth of horizon in units of centimeters yielding densities with units of grams per cubic centimeter (g/cm^3).

Soil Grinding and Sieving

After oven drying and weighing for bulk density, each sample was ground to pass through a 2 mm sieve and mixed to achieve a homogenous sample. Ground soil fell onto a 2 mm sieve by which the soil could be separated into two size fractions: greater than 2 mm diameter particles (coarse fragments) and less than 2 mm diameter particles. Each were bagged (plastic-lined paper bags) and labeled accordingly.

Figure 12. The pH meter used in method described.

Measurement of pH in H_2O and 0.01 M KCl

Soil pH was measured in two solutions: deionized H_2O and 0.01 M KCl modified from Jones (2001). The use of KCl solution was to provide a more stable pH reading. Also the difference between pH readings in H_2O and 0.01 M KCl may be used to indicate exchange capacity in the soil (net positive or net negative).

Materials used included: small glass jars (approximately 50 mL), pH meter/electrode (Figure 12), two-decimal-place balance, two wash bottles (one for deionized H_2O and one for KCl solution), deionized water, freshly prepared 0.02 M KCl (Potassium Chloride) solution, and pH buffer solutions of pH 4, 7, and 10.

The pH meter was calibrated using the pH buffer solutions every morning before use that day, although the manufacture of the pH meter recommended regular calibration at least every two weeks.

Fifteen glass jars were labeled and placed in a row. Each was placed on the balance and 10 g of an air-dry soil sample (previously ground to pass through a 2 mm sieve) was poured into the jars.

For efficiency, the measurements were staggered. Each activity performed was on a two minute interval between samples. A timer was employed to accurately stay on schedule.

Every two minutes, a jar with sample would be placed on the balance and approximately 10 g of deionized H_2O was added. The jar was then swirled vigorously. The jars containing the soil and water solution were swirled as often as possible in between the activities (approximately eight times in a 30 minute period.

After 30 minutes, a sampled would be swirled one last time and pH measured using the pH meter. The electrode was completely submerged in the soil and water solution but above the soil sediment that settled to the bottom. It would take about 30 to 45 seconds for the reading to stabilize. The pH value was recorded in the lab notebook. The pH electrode was rinsed with deionized water in between each use.

Immediately following the recording of the pH of the soil and water solution, the glass jar was placed on the balance and approximately 10 g of the 0.02 M KCl solution was poured into the glass jar. The jar was again vigorously swirled. This mixture creates a solution of soil and 0.01 M KCl. The jar was then placed aside and this stage of the procedure was repeated for the next jar of sample.

Again the jars were swirled as often as possible in between the activities (approximately eight times in a 30 minute period. After 30 minutes, the pH meter/electrode was used to measure pH in the soil and 0.01 M KCl solution. Again, the electrode was completely submerged in the solution but above the soil sediment. After waiting about 30 to 45 seconds for the reading to stabilize, the pH was recorded in the lab notebook. Waste solution was then disposed of properly. The whole procedure could then be repeated with dry glass jars for the next fifteen soil samples.

Organic Carbon – Loss on Ignition

The loss on ignition method described in Konen et al. (2002) was used for measuring the amount of organic matter in the soil samples of each horizon. The equation from Konen et al. (2002) was also used for predicting soil organic carbon (SOC) for Iowa soils based on soil organic matter (SOM) content. This equation is valid for soils in the NRCS's Major Land Resource Area (MLRA) 103 (aka. Des Moines Lobe). Three of the four locations: Hallett, Wildin, and Jenkins were located in MLRA 103. The Avon Lake location is located only four miles away from the edge of the DML. This same equation was used for all four locations to predict SOC.

Twenty-three labeled crucibles were weighed empty and weight recorded in the lab notebook. In accordance with Konen et al. (2002), approximately 8 g (+/- 0.2 g) of ground (< 2 mm) air-dry soil was scooped into each crucible except one that was to remain empty. Crucibles were then weighed with the added soil. All crucibles were placed in a round crucible tray and oven dried at 105 ˚C for a minimum of 2 hours. After drying, the crucibles were placed in a desiccator to cool to a temperature that could be safely handled. Crucibles with oven-dry soil were then removed one at a time and weighed on the balance.

All crucibles were then loaded into a rectangular metal tray. This tray was used only as a way to make insertion and extraction from the muffle furnace easier. Once trays were loaded into the muffle furnace, the furnace was set to 360 ˚C and samples were dried for 2 hours (Konen et al., 2002 and Cambardella et al., 2001). This temperature and length of heating has been demonstrated to be reliable for delivering reproducible results without being too hot to cause the loss of CO_2 from carbonates and the loss of structural water from clay minerals. (Cambardella et al., 2001). The 2 hours began as soon as the furnace reached 360 ˚C. After 2 hours, the heat was turned off and samples allowed to cool until they were cool enough to remove.

All crucibles were then transferred to a crucible tray and placed in the drying oven again to dry at 105 ˚C for a minimum of 2 hours. They were removed and placed in a desiccator to cool. They were then weighed a final time to obtain the weight of crucible and soil after loss on ignition.

Percent SOM was calculated by first subtracting the mass of furnace-treated soil and crucible from the mass of oven-dry soil and crucible. The difference was then divided by the mass of oven dry soil and then multiplied by 100%.

$$\%SOM = \frac{\text{oven-dry soil and crucible mass} - \text{furnace soil and crucible mass}}{\text{oven-dry soil and crucible mass} - \text{crucible mass}} * 100\%$$

Equation 3.

To predict SOC for these Iowa soils, the equation from Konen et al. (2002) was used. Soil organic matter first had to be expressed in units of grams of SOM per kilogram of soil. This was then plugged into Equation 4 (modified from Konen et al., 2002).

$$\%SOC = \frac{0.6824 * g\ of\ SOM\ /\ kg\ of\ soil - 2.8698}{10}$$

Equation 4.

Inorganic Carbon – Gravimetrical Analysis

Inorganic carbon in soil is normally comprised of the minerals calcite ($CaCO_3$) and dolomite ($CaMg(CO_3)_2$) in most cases. To a large extent, the presence of these minerals within an Iowa soil is indicative of youth and/or less chemical weathering.

A procedure modified from the work of Dreimanis (1962) was used by the author to measure the weight of carbonate minerals in the soil horizon samples. Both procedures involve the reaction of a soil sample (potentially containing carbonates) with an acid. The method used varies from Dreimanis (1962) primarily in that the weight of sample lost to reaction is measured versus measuring the volume of CO_2 produced by the reaction.

For efficiency, twelve samples were processed following this procedure in a staggered sequence with a 2 minute interval between activities performed on each sample. Primary preparations included: labeling the twelve glass beakers that would contain the soil samples, filling twelve additional glass beakers each with approximately 25 mL of 6 N HCl, laying out twelve weighing boats, and laying out twelve watch glasses.

First, each of the twelve beakers was weighed and their weights recorded on the lab sheet or notebook. Next, eleven of the twelve sample beakers would be filled with 2 g of different soil samples and the weight again recorded. Normally one beaker was left empty in each run. This helped to determine relative loss of mass due to evaporation of the acid solution over the course of the run. Within each weighing boat was placed a beaker containing soil, a beaker of HCl, and a watch glass. All weighing boats were placed under a fume hood.

A timing schedule was then made. A "time zero" was written down for each sample offset by 2 minutes. The weighing boat containing the first sample was then placed on the mass balance and its total weight recorded as its "time zero weight". At exactly time zero for a sample, the acid was poured into the soil sample beaker and swirled vigorously to allow for complete surface area coverage of the soil particles by the acid. The beaker was then quickly placed back on the balance, and 30 seconds after time zero, the total weight was again recorded. Any loss in mass over these first 30 seconds is understood to be primarily due to the reaction of calcite ($CaCO_3$) with the HCl since it is more readily reactive to the acid (Dreimanis 1962).

Every 2 minutes, the mixing and weighing was performed for each sample in sequence until they were all mixed. Samples were re-swirled approximately every 4 minutes to insure the completeness of the chemical reaction.

Thirty minutes after time zero, each weighing boat was again placed on the balance and weight recorded. Any loss in mass over the previous 29.5 minutes is understood to be primarily due to the reaction of dolomite ($CaMg(CO_3)_2$) with the HCl since it is less readily reactive to the acid (Dreimanis, 1962). However, on such a small sample with complete submergence in excess HCl, all dolomite should be dissolved and reacted to release CO_2 gas.

Over the course of the 30 minutes that it would take to complete an experimental run, some of the water in the HCl solution would evaporate leading to a loss in total mass and a potential misrepresentation of the abundance of carbonates present. To account for the mass of water lost to evaporation, an empty beaker was used in place of a sample beaker and treated exactly the same. Acid was poured into this empty beaker, swirled, and resultant mass recorded after 30 minutes. There would be a loss of mass on the order of a few hundredths of a gram. To correct for this, the amount of water mass lost to evaporation in the run was measured and subtracted from the measured mass of CO_2 lost due to chemical reaction.

Weight of calcite and dolomite and percent of calcite and dolomite could then be calculated using Equations 5 through 8. To prevent the reporting of false positive measurements of carbonates, a detection limit of 1.00% was set. As such, any measurements of total carbonates below 1.00% were treated as containing no carbonate minerals.

$$\%CaCO_3 = \frac{\text{g } CO_2 \text{ lost @30sec}}{\text{g dry soil}} * \frac{\text{g } CaCO_3 \text{ mol}^{-1}}{\text{g } CO_2 \text{ mol}^{-1}} * 100\%$$

Equation 5.

$$\%CaCO_3 = \frac{\text{g } CO_2 \text{ lost @30sec}}{\text{g dry soil}} * 2.273 * 100\%$$

Equation 6.

$$\%CaMg(CO_3)_2 = \frac{\text{g } CO_2 \text{ lost @30min} - \text{g } CO_2 \text{ lost @30sec}}{\text{g dry soil}} * \frac{\text{g } CaMg(CO_3)_2 \text{ mol}^{-1}}{\text{g } CO_2 \text{ mol}^{-1}} * 100\%$$

Equation 7.

$$\%CaMg(CO_3)_2 = \frac{g\ CO_2\ lost\ @30min - g\ CO_2\ lost\ @30sec}{g\ dry\ soil} * 2.095 * 100\%$$

Equation 8.

Soil Particle Size

Soil texture

Soil particle size, more commonly referred to as soil texture is a key soil property that influences almost every other property. Soil texture is determined by examining only the particles within the less than 2 mm size fraction (fine earth fraction). Soil particle sizes measured included: clay (< 2 µm), silt (2-53 µm), and sand (53-2000 µm).

Sixteen labeled ~500 mL glass bottles were placed out. 10.0-10.2 g of air dry soil sample were placed in each bottle with the weight of soil, soil sample ID, and bottle number recorded. A soil standard was placed in one of the bottles with the other 15 receiving soil samples for analysis. Samples from soils that exhibited mollic colors (Munsell value and chroma of ≤ 3), and therefore likely rich in SOM, received a treatment of 30% H_2O_2. These dark colored samples were moistened with about 10 mL of deionized water, and then given of dose of approximately 10 mL of 30% H_2O_2. Each bottle treated was then covered with a watch glass (to limit evaporation) and placed in a sand bath on top of the hotplate with a temperature of about 70 ˚C.

The H_2O_2 was allowed to react with the SOM overnight with the bottle still resting in the warm sand bath. If the following morning, any sample did not appear light brown or grey in color, then it received another dose of H_2O_2 and allowed to react again until the majority of SOM in the soil was oxidized. The SOM is necessary to remove from the soil since it helps to hold soil aggregates together. Any excess H_2O_2 was allowed approximately a day to chemically decompose while the bottle still sat in the warm sand bath.

After any necessary treatment of the mollic-colored samples mentioned above, all glass bottles containing soil samples were given exactly 10.0 mL of a sodium hexametaphosphate solution. All bottles were then filled approximately half-full and sealed with a rubber stopper. They were then placed on an electric shaker and agitated overnight (about 15 hours).

Bottles were then removed from the shaker and filled with deionized water to a total volume of 400 mL of soil, sodium hexametaphosphate, and water. All sixteen bottles were then placed in a line on a countertop. A time schedule was then made with 1 minute intervals. At time zero, the first bottle of sample would be agitated for 1 minute with the plunger to thoroughly mix all soil particles within the fluid. This was repeated for each of the sample bottles.

Upon completion of the mixing with the plunger, the average temperature of the soil solutions and the temperature of "room temperature" water were measured and compared. If they were not the same temperature, the midpoint temperature between them was used to determine the settling time of soil particles based on Stoke's Law. The necessary time for all silt-sized particles to settle below 5 cm from the surface of the solution was allowed to elapse (usually around 3.5 hours).

Pre-weighed, labeled crucibles for each sample were set out. At the exact settling time determined previously for the first sample, a 5 mL aliquot was pipetted from a depth of 5 cm below the surface of the solution within the bottle. The aliquot was then released into its respective crucible. The pipette would be rinsed to ensure the collection of all the suspended clay particles. The remaining samples were then also pipetted according to the time schedule at one minute intervals.

Following pipetting, the crucibles containing the sample aliquots were set in a crucible tray and placed in a drying oven set to 105 ˚C and allowed to dry for 24 hours. Once dry, the crucibles were removed from the oven and immediately placed in a desiccator to allow them to cool enough to be handled. One at a time, a crucible was removed from the desiccator (with lid quickly replaced) and placed on the four-decimal-place balance and it weight recorded on the data sheet or lab notebook.

The remaining soil solution in each of the glass bottles was then poured into a 53 µm sieve. Each sample's sediment was rinsed with copious amounts of deionized water to remove the silt- and clay-sized particles. The remaining soil particles left on the sieve represented the sand fraction for its respective soil sample. This sand was then transferred to a pre-weighed, labeled glass beaker. All beakers were then placed in the drying oven at 105 ˚C to dry for approximately 24 hours.

After drying, the glass beakers containing the sand were removed from the oven and allowed to cool until safe to handle. Each beaker was then placed on the two-decimal-place balance and its weight recorded. The proportions of the three major particle size fractions (sand, silt, and clay) could now be calculated (Equations 9-11).

$$\%\ \text{sand} = \frac{\text{sand and beaker mass} - \text{beaker mass}}{\text{dry mass of soil sample}} * 100\%$$

Equation 9.

$$\% \text{ clay} = \frac{(\text{oven-dry mass of clay, salt}_{(NaPO3)6}\text{, and crucible - salt mass - crucible mass}) * 80}{\text{dry mass of soil sample}} * 100\%$$

Equation 10.

$$\% \text{ silt} = 100\% - \% \text{ clay} - \% \text{ sand}$$

Equation 11.

Sand fractions

To further determine the distribution and abundance of the soil particles, the sand fraction from above was run through additional sieves. This allowed for the sand to be separated into five different size fractions: very fine sand (53-125 µm), fine sand (125-250 µm), medium sand (250-500 µm), coarse sand (500-1000 µm), and very coarse sand (1000-2000 µm).

First, the appropriate sized sieves were placed on a two-decimal-place balance and their weights recorded. After weighing, they were stacked into a nest. Then a glass beaker of sand from a sample was poured into the top sieve. The nest of sieves was then placed in a sieve shaker and were shaken for 2 minutes. Following the shaking, each sieve was separated and placed on the two-decimal-place balance and weight was recorded. The proportion of sand in each size fraction could now be calculated such as in Equation 12 below.

$$\% \text{ fine sand} = \frac{\text{fine sand and sieve mass} - \text{sieve mass}}{\text{dry mass of soil sample}} * 100\%$$

Equation 12.

Coarse fragment fraction

The proportion of coarse fragments (> 2 mm diameter) contained within a soil horizon was of interest since this project was interested in the breakdown of coarse sands and gravels to finer particles. The proportion of coarse fragments may also affect the texture class as well. If the coarse fraction equals or exceeds 35% of the soil, a modifier such as “gravelly” will need to be added to the texture class. For example, a “sandy loam” with 42% medium-sized gravel would be called “medium gravelly sandy loam” (Schoeneberger et. al, 2012).

Proportion of coarse fragments was easily calculated. First, an empty tin was weighed on a two-decimal-place balance. Next the coarse fragment size fraction from the soil was poured into the same tin. The tin was then reweighed.

To calculate, the weight of the empty tin was subtracted from the weight of the tin and coarse particles. The result was then divided by the weight of the entire oven-dried soil horizon (that was previously measured to calculate bulk density) and then multiplied by 100%.

$$\%\ \text{coarse frags} = \frac{\text{tin and coarse frags mass} - \text{empty tin mass}}{\text{oven-dry soil mass}} * 100\%$$

Equation 13.

Thin Section Preparation

In order to better know the mineralogy of the various soils collected and to observe weathering fronts of the coarse particles, thin sections of the soils were made. Sixty-seven thin sections in total were prepared by Spectrum Petrographics Inc. of

Vancouver, WA. Due to budget and time constraints, not every horizon of every soil core could have a thin section made for it.

It was determined by the author that three thin sections per core would be sufficient to make good comparisons. The three thin sections from each core would represent the A horizons, B horizons, and C horizons (if present).

The intact duplicate cores were sourced for the thin sections. For each core, the vertical length of all the A horizons combined was measured. A mostly-rectangular prism was then delicately cut out of the soil core centered at the determined midpoint of the A horizons. The removed sample of soil would measure approximately 4 cm (vertical) by 2 cm by 2 cm. The sample was then placed (upside in the up position) in a labeled, small wax-paper cup which in turn was placed in a labeled, small plastic container with lid. This process was repeated for the B horizon(s) present in the core and for the C horizon(s) present in the core. It is important to mention that for pragmatic reasons, AB horizons and AC horizons were treated as an A horizon and a BC horizon was treated as a C horizon.

The above procedure was repeated for each of the 25 cores collected for this study. Due to the lack of C horizons in some cores, only 67 samples were collected from the cores. After all samples were collected, the plastic cups were packaged in a box and shipped to Spectrum Petrographics Inc. in Vancouver, WA.

Analysis of Soil Thin Sections

Once thin sections prepared from the soil samples were received, various analyses were performed. These included a study of all thin sections noting general observations in particular areas explained below, an estimate of the abundance of certain mineral and non-mineral groupings using a computer program (cellSens Dimension by Olympus), and mineral counts conducted on three slides from one ideal soil profile to gain insight on mineral assemblages.

To aid the aforementioned analyses and for illustrative purposes, mosaic photographs were made of each soil thin section slide using an Olympus brand petrographic microscope equipped with a photo-capture device (Figure 13). The microscope camera fed images into an Olympus brand computer program cellSens Dimension. This program was used to scan each slide under 2x magnification and stitch together a mosaic image.

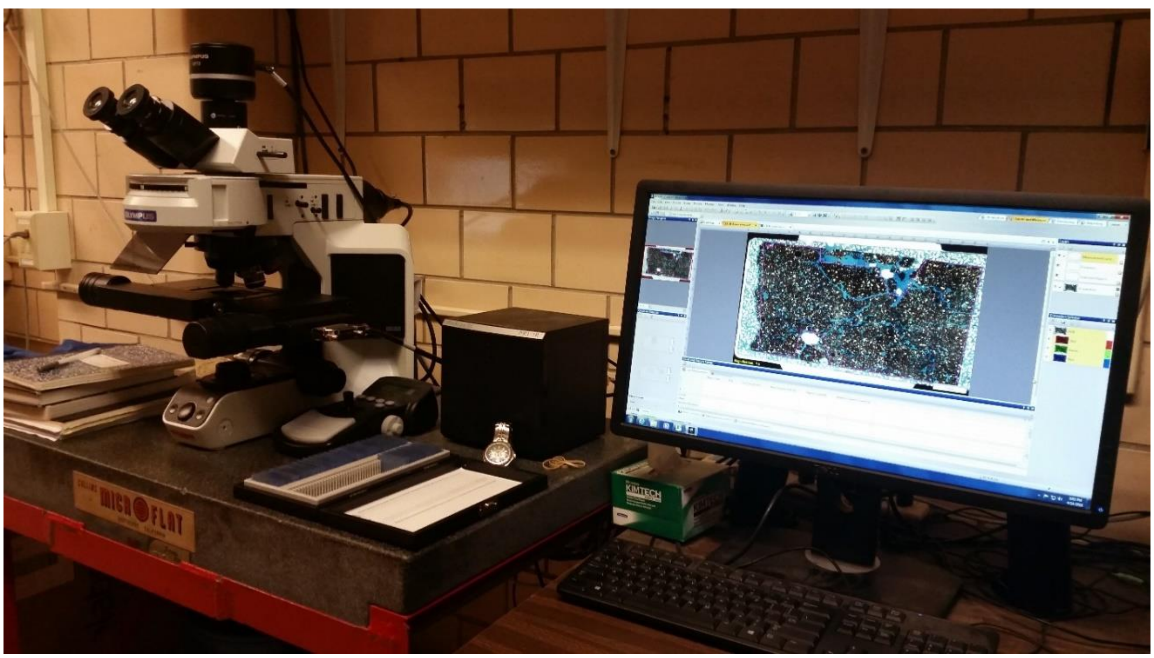

Figure 13. Petrographic microscope and image analysis program on computer.

General observations

A study of all thin sections noting general observations in the areas of particle size assemblage, porosity, sorting, chemical and physical weathering on coarse particles, relative organic matter abundance, integrity of original soil structure and amount of damage to structure generated during thin section preparation, and any other prominent features that commanded attention. Photographs of features of interest were also collected. Photos were taken of primarily unidentified particles and any evidence of chemical weathering or breakdown of feldspar grains.

Mineral and non-mineral estimation

To gain some sense of the abundance of certain minerals in the sand and pebble fraction, the computer program cellSens Dimension by Olympus was used to make quick estimates of the abundance of certain mineral and non-mineral groupings. The four groups were “colorless minerals”, “pore space”, “clay/silt/OM/other”, and “brown concretions”. Using the program (Figure 13), colors occurring in an image to be analyzed could be assigned to one of these groupings.

First, an overview mosaic image of the whole thin section slide was opened. Using the “Count and Measure” tools, a ROI (region of interest) was created by drawing a polygon on the image. Polygons were primarily only drawn on areas of the slide that contained soil exhibiting relatively undisturbed soil structure to eliminate errors associated with estimating the pore space. Screenshots of each ROI on each slide was saved after completion of analysis (e.g. Figure 47).

The pixels had to be sorted by color into the different groups. The “colorless minerals” contained the white to light tan colors, “pore space” contained the blue colors due to the blue dyed resin, “clay/silt/OM/other” contained the brown colors, and “brown concretions” contained the very, very dark brown to black colors. Any other colors occurring in the slide were not counted into these groupings. Colors were regularly tweaked for the analysis of each slide. This was made necessary by the uniqueness of each slide’s mosaic photo resulting from things such as the camera’s exposure time.

The program then summed all the color pixels assigned to a grouping in the image. Results were reported for area in units of square micrometers (μm^2) and for percent of total area (%).

Mineral counts on subsample

Mineral counts were conducted on three slides from one ideal soil profile to gain insight on mineral assemblages. The three slides represented the A, B, and C horizons. Counts were conducted by using the Gazzi-Dickinson point counting method as described in Ingersoll et al. (1984). However, the method was modified to save time by only doing 100 counts per slide.

A 10 by 10 grid (with approximately 1.2 mm spacing) was placed over the mosaic images of each slide (Figure 49). The particle under each intersection was identified and assigned to one of the following categories: quartz, feldspar, pore space, clay/silt/OM, brown concretion, carbonates, or other lithic particles. If the intersection point was on top of a particle consisting of several mineral crystals (e.g. a granite pebble), only the mineral crystal directly under the intersection point was recorded in accordance with Ingersoll et al. (1984).

Estimate of Mass of Carbonates Lost and Resultant Bulk Density

Presumably there were carbonate minerals scattered throughout the outwash deposit all the way to the surface at the time of deposition. Therefore a method was devised to approximate the mass of calcareous materials removed by reaction and dissolution from the upper solum.

To estimate the mass of carbonates removed from the soil zone from the surface to the depth of effervescence, four key pieces of information must be known. These are the depth to carbonates/effervescence, bulk density of outwash, percent carbonates in outwash sediments, and fraction of retention of freed calcium and magnesium. Equation 14 shows how this estimate was made by multiplying the fractions of calcite and dolomite in the outwash by their respective fractions of mass removed which was then multiplied by the bulk density of the outwash and the depth to carbonates.

The starting outwash bulk density, percent carbonates, and the fraction of released calcium and magnesium remaining allows for a prediction of the resultant bulk density following removal of the carbonate minerals. Equation 15 shows how this prediction was made by multiplying the fractions of calcite and dolomite in the outwash by their respective fractions of mass removed which was then multiplied by the bulk density of the outwash.

$$\left(\frac{\underline{g\ CaCO_3}}{1\ g\ outwash} * 0.800 + \frac{\underline{g\ CaMg(CO_3)_2}}{1\ g\ outwash} * 0.825\right) * \frac{\underline{g\ outwash}}{cm^3} * \frac{\underline{10^8\ cm^2}}{1\ ha} * cm\ to\ carb. * \frac{\underline{1\ Mg}}{10^6\ g} = \frac{\underline{Mg\ carb.}}{ha}$$

Equation 14.

$$\left[1 - \left(\frac{\underline{g\ CaCO_3}}{1\ g\ outwash} * 0.800 + \frac{\underline{g\ CaMg(CO_3)_2}}{1\ g\ outwash} * 0.825\right)\right] * \frac{\underline{g\ outwash}}{cm^3} = \frac{\underline{g\ soil}}{cm^3}$$

Equation 15.

Statistical Analyses

Simple statistics were performed on most of the data gathered as part of this study. These statistics are presented in the results and discussion chapter of this thesis. They include mean, median, standard deviation and Student's t-tests. This study utilized the most conservative approach to the Student's t-test. All t-tests were performed for a two-tailed distribution and with two-sample unequal variance.

CHAPTER 3

RESULTS AND DISCUSSION

Table 4 displays the compilation of almost all data gathered for each outwash soil sample organized by unique identification numbers. The first letter in the ID denotes the location (i.e. Hallett, Wildin, Jenkins, Avon Lake). The first number denotes the coring site at the location. The second letter denotes which of the two cores A or B from the site. Lastly, the second number denotes the number of the soil horizon from the profile. For example, H2B-3 would represent soil sampled from the third horizon of core B at coring site 2 of Hallett.

An additional note: many of the sections to follow contain tables of statistics comparing A and B horizons. For the purpose of simplifying these comparisons, AB and AC horizons are treated exclusively as A horizons. BA and BC horizons are likewise treated exclusively as B horizons.

Soil Profile Descriptions

In total, 25 soil cores were thoroughly described. The data from 18 profiles were combined to estimate average values for physical parameters to provide a synopsis of the prevalent morphological features and physical properties of each master horizon at three of the locations (Table 5). All 25 profiles are listed as Tables 1 through 25 in Appendix A. However, seven profiles were not used in this study for reasons mentioned below (i.e. not derived from outwash).

Table 5 gives a snapshot of the outwash derived soils across the three study locations. Typically A horizons were loams or clay loams, B horizons were sandy loams to gravelly loamy sands, and C horizons were gravelly loamy sand to sand. It shows that clay amounts do not change much within the horizons from the northwest to the southeast. The percent clay in the A horizons are around 24% and the percent clay in the B horizons are around 15-21%. If waning flow or overbank deposits are responsible for the texture difference between the upper profile and lower profile as Bettis and Hoyer (1986) suggest, then this increase in clay makes logical sense. More clay would have been deposited if the meltwater flow energy was decreased.

Table 5 also shows that geometric means (mean particle sizes) are highest for Wildin followed by Hallett followed by Avon Lake. Similarly, the fraction of coarse fragments is the least at Avon Lake; however, they were very comparable for Hallett and Wildin. Mollic colors were observed fairly deep (Table 5) and increased in depth from 50 cm at Hallett to 60 cm at Wildin to 90 cm at Avon Lake showing deeper soil development likely due to the increases in MAP and MAT in a southeasterly trend.

Soil map accuracy

NRCS soil survey maps used to aid in the identification of sampling sites proved to be not very accurate. Of the 25 profiles, only seven were the dominant soil series that were said to occur in the location’s respective consociation. Ten were identified to belong to geographically associated soils or otherwise similar/competing soil series that are commonly listed on the NRCS official series descriptions. The other eight remaining sampled soils were identified to be very different from what the soil map would suggest and as such were either in a different soil order or suborder as can be observed in Tables 1 through 25 in Appendix A. Interestingly enough, the farther north the soil map, the more accurate the mapping was observed to be. This is based on the number of sites containing the appropriate series or a very similar/competing series.

This evidence suggests a complex variability in soils occurring across these outwash terraces. Accurate mapping of soils across any landscape is often challenging. An outwash terrace is clearly no exception. Mapping accuracy is likely complicated by lack of much relief (e.g. only 5 m difference between highest and lowest points across a linear distance of about 700 m at the Wildin location) and the at times complex history of natural and human events that influence the morphology and properties of these soils.

Outwash soils: yes or no?

All locations were sampled based on their meeting the three main criteria: appropriate age and landform based on surficial geology maps (Quade et al. 2001, Quade et al. 2002, Quade et al. 2003, Quade et al. 2004), outwash derived soil series mapped by NRCS (Web Soil Survey, 2016), and ground truthing to assess suitability. After profiles and analyses data were examined, some soils were confirmed to have been formed in outwash while others were not, and therefore had to be eliminated from any comparisons within this study. The paragraphs below detail the findings in this regard.

Hallett

Of the eight sola sampled at the Hallett location, seven formed in outwash. These soils are very sandy and gravelly (Tables 1-2, 4-8 in Appendix A). These soils were

Table 4. Compilation of data gathered in all analyses for all horizons of the sampled outwash derived sola.

											Fine earth fraction sand				
Series	ID	Horizon	Horizon depth (cm)	Horizon thick. (cm)	Texture	% Sand	% Silt	% Clay	% Coarse fragments	Geometric mean (µm)	% v. coarse	% coarse	% medium	% fine	% v. fine
Wadena	H1A-1	Ap	36	36	CL	28.7	41.5	29.8	1.4	108	1.9	2.3	6.3	10.8	7.0
	H1A-2	2A	46	10	L	44.8	31.4	23.8	13.8	262	9.6	6.2	8.6	12.5	7.6
	H1A-3	2Bw	52	6	VGr SCL	54.2	23.2	22.6	53.1	336	12.3	9.9	10.7	12.9	8.1
Dakota	H2B-1	Ap	18	18	L	49.1	29.3	21.7	0.7	148	1.0	3.8	12.9	20.7	10.6
	H2B-2	A	58	40	L	35.6	38.1	26.3	0.1	113	0.9	2.9	8.7	15.2	8.0
	H2B-3	AB	75	17	L	51.2	29.4	19.4	1.8	190	3.9	4.3	11.2	21.3	10.3
	H2B-4	BA	90	15	SL	58.8	21.8	19.4	3.6	207	3.8	5.7	11.7	25.2	12.3
	H2B-5	Bt	127	37	SCL	46.9	26.9	26.1	1.8	180	3.8	5.3	9.3	17.5	11.0
	H2B-6	2BC	137	10	Gr SL	67.3	14.4	18.3	24.5	309	10.9	5.3	9.6	29.8	11.7
Wadena	H4B-1	Ap	17	17	CL	38.6	34.1	27.3	2.6	225	5.8	9.7	9.4	8.4	5.4
	H4B-2	A	44	27	SCL	49.2	27.5	23.3	4.2	286	9.0	9.7	11.4	11.4	7.6
	H4B-3	2BC	56	12	Gr SL	75.5	12.7	11.7	39.7	728	34.8	20.0	9.6	6.6	4.5
Estherville	H5B-1	Ap	16	16	L	40.1	34.5	25.3	2.6	226	5.7	9.2	10.9	8.8	5.0
	H5B-2	A1	27	11	L	46.2	30.6	23.2	4.7	252	5.3	11.8	13.7	10.1	5.0
	H5B-3	2A2	41	14	Gr SL	61.6	20.3	18.1	22.5	385	11.7	15.6	16.0	11.5	6.5
	H5B-4	2Bw	55	14	VGr SL	79.7	9.8	10.5	43.5	662	26.1	25.1	16.0	8.3	3.8
	H5B-5	2BC	61	6	VGr SL	73.7	20.1	6.2	39.7	627	26.1	22.0	12.2	7.4	5.8
Estherville	H6B-1	Ap	22	22	SL	67.7	17.4	14.9	4.4	377	9.7	15.8	19.8	15.7	5.6
	H6B-2	2Bw1	47	25	VGr SL	78.3	10.7	11.0	35.4	552	19.8	20.0	19.7	13.0	5.8
	H6B-3	2Bw2	49	2	Gr LS	77.9	14.2	7.9	25.5	553	18.7	23.5	19.2	8.8	5.6
Estherville	H7B-1	Ap	22	22	SL	59.0	23.8	17.2	5.5	359	9.9	15.6	16.3	10.9	5.9
	H7B-2	2Bw	40	18	VGr SL	64.0	20.2	15.9	40.1	434	15.1	16.1	14.9	10.8	6.6

Table 4. Continued

Series	ID	Horizon	Horizon depth (cm)	Horizon thick. (cm)	Texture	% Sand	% Silt	% Clay	% Coarse fragments	Geometric mean (µm)	Fine earth fraction sand % v. coarse	% coarse	% medium	% fine	% v. fine
Wadena	H8A-1	Ap	21	21	CL	28.7	34.8	36.5	0.9	144	3.6	4.8	7.2	7.2	5.1
	H8A-2	A	48	27	CL	33.5	35.4	31.1	3.4	171	3.9	6.5	9.3	8.3	5.0
	H8A-3	2Bw	70	22	Gr SCL	54.1	22.6	23.2	31.5	362	13.0	12.1	12.7	9.7	5.8
	H8A-4	2BC	78	8	EGr SL	68.2	19.7	12.1	65.6	612	28.3	16.0	11.8	6.9	4.6
Cylinder	W1A-1	A1	16	16	SCL	50.7	27.3	22.0	5.0	323	9.3	15.2	10.8	8.4	6.3
	W1A-2	A2	52	36	SCL	49.5	26.1	24.4	4.3	347	12.6	13.0	8.7	8.0	6.5
	W1A-3	2A3	62	10	Gr SL	66.9	14.3	18.8	28.7	627	28.9	19.1	8.5	5.5	4.3
	W1A-4	2Bw	71	9	VGr SL	74.2	11.3	14.5	38.5	705	33.7	19.1	10.0	6.1	4.5
	W1A-5	2BC	82	11	VGr SL	75.0	15.9	9.1	35.6	805	40.7	21.0	6.7	3.1	2.7
	W1A-6	2C	99	17	VGr SL	73.1	17.4	9.6	39.0	632	24.3	27.5	11.8	4.8	4.0
Cylinder	W2B-1	A1	13	13	L	46.9	31.2	21.9	8.5	282	8.5	9.9	13.1	9.7	5.2
	W2B-2	A2	34	21	L	43.9	31.2	24.9	5.2	183	2.6	6.7	14.8	12.5	6.6
	W2B-3	2AB	63	29	VGr SL	64.6	16.2	19.2	42.6	383	12.2	12.5	19.1	13.8	6.3
	W2B-4	2BC	70	7	VGr SL	72.0	17.4	10.6	49.7	470	17.9	12.0	18.6	16.8	5.8
Estherville	W3A-1	A	30	30	SCL	55.0	24.1	20.9	10.0	319	9.0	13.2	13.0	12.5	7.8
	W3A-2	2Bw	50	20	VGr SL	78.6	9.0	12.4	44.9	813	40.3	21.3	9.4	5.1	2.9
	W3A-3	2BC	64	14	Gr LS	81.6	10.2	8.2	31.0	886	44.2	24.2	8.2	3.4	1.9
	W3A-4	2C1	76	12	VGr LS	87.1	7.1	5.8	36.5	960	47.2	28.8	7.4	2.6	1.4
	W3A-5	2C2	104	28	Gr SL	78.6	11.0	10.5	32.8	637	21.8	30.4	16.9	6.5	3.3
Spillville	W4A-1	Ap	22	22	L	45.1	30.3	24.5	1.7	247	7.2	8.9	9.5	11.5	8.5
	W4A-2	A1	55	33	CL	35.8	34.2	30.0	1.2	175	4.4	5.8	8.3	9.6	8.1
	W4A-3	A2	91	36	CL	29.9	37.8	32.3	1.6	176	5.0	5.7	8.5	6.4	4.8
	W4A-4	2AC1	108	17	VGr SCL	63.6	13.2	23.2	37.6	512	21.2	16.0	13.6	8.0	4.9
	W4A-5	2AC2	138	30	Gr SL	78.7	5.7	15.6	25.7	654	27.9	19.9	16.4	10.5	4.2

Table 4. Continued

Series	ID	Horizon	Horizon depth (cm)	Horizon thick. (cm)	Texture	% Sand	% Silt	% Clay	% Coarse fragments	Geometric mean (µm)	Fine earth fraction sand % v. coarse	% coarse	% medium	% fine	% v. fine
Warsaw	W5B-1	A1	32	32	L	47.7	30.5	21.8	0.8	207	4.2	8.1	10.7	13.8	11.3
	W5B-2	A2	58	26	SCL	50.6	26.4	23.1	10.7	230	6.1	7.6	9.6	14.9	12.5
	W5B-3	2BA	75	17	VGr SCL	65.4	13.5	21.1	35.2	415	13.4	16.5	14.8	13.0	8.2
	W5B-4	2Bt	83	8	Gr CL	35.3	36.8	28.0	18.6	309	12.4	10.8	6.1	3.4	3.1
	W5B-5	2C	119	36	Gr LS	81.1	9.7	9.3	33.4	551	15.2	27.4	25.1	9.4	4.4
Cylinder	W6C-1	A1	16	16	L	41.1	33.8	25.0	2.0	193	1.9	9.2	17.6	8.7	4.2
	W6C-2	A2	43	27	SCL	49.1	26.5	24.3	1.9	231	3.2	9.5	21.9	10.8	4.2
	W6C-3	2Bw	66	23	VGr SL	69.9	10.9	19.2	35.3	548	20.1	21.2	17.7	7.8	3.4
Wiota	A1A-1	Ap	13	13	L	33.7	44.7	21.6	0.0	114	0.2	1.8	13.7	15.6	4.7
	A1A-2	A1	29	16	L	30.1	43.0	26.9	0.0	97	0.0	1.8	11.6	13.3	3.7
	A1A-3	A2	42	13	CL	20.1	46.7	33.3	0.0	80	0.0	1.3	9.4	10.6	2.3
	A1A-4	AB	67	25	CL	22.2	39.8	38.0	0.0	77	0.0	1.4	8.6	10.7	2.4
	A1A-5	Bt	90	23	C	24.1	27.6	48.4	0.0	75	0.2	1.0	8.2	12.3	2.8
	A1A-6	2BC	114	24	SCL	64.9	7.3	27.8	0.8	189	0.5	3.2	23.7	33.3	4.9
	A1A-7	2C	196	82	LS	87.7	1.7	10.7	4.7	375	2.8	17.9	40.5	23.5	3.5
Fort Dodge	A2A-1	Ap1	9	9	L	44.5	34.2	21.3	0.0	138	0.0	2.5	18.7	18.7	4.8
	A2A-2	Ap2	22	13	L	44.9	31.4	23.7	0.0	135	0.1	2.1	18.2	19.5	5.1
	A2A-3	A	55	33	SCL	54.0	23.9	22.1	0.0	155	0.0	2.5	20.8	24.9	5.6
	A2A-4	AB	78	23	SCL	58.6	20.4	20.9	0.0	174	0.2	2.7	23.1	28.4	5.8
	A2A-5	Bw	97	19	SL	68.7	13.4	18.0	0.0	206	0.5	3.3	26.8	34.5	6.0
	A2A-6	2C	147	50	LS	87.1	3.5	9.4	1.8	304	1.8	8.9	37.6	33.3	6.5

Table 4. Continued

Series	ID	Horizon	Horizon depth (cm)	Horizon thick. (cm)	Texture	% Sand	% Silt	% Clay	% Coarse fragments	Geometric mean (µm)	Fine earth fraction sand % v. coarse	% coarse	% medium	% fine	% v. fine
Fort Dodge	A3B-1	Ap1	13	13	L	31.7	47.3	21.0	0.1	127	0.3	4.5	15.2	8.6	2.7
	A3B-2	Ap2	27	14	L	29.7	46.7	23.6	0.0	122	0.2	4.7	14.0	8.3	2.5
	A3B-3	A	51	24	L	48.5	31.2	20.3	0.0	197	0.4	8.7	23.4	13.7	4.2
	A3B-4	BA	77	26	SL	55.1	25.8	19.1	0.1	225	1.1	10.1	24.4	15.7	4.8
	A3B-5	2Bw	95	18	SL	66.6	16.7	16.6	1.3	300	4.6	12.1	25.6	18.9	5.0
	A3B-6	2BC	106	11	LS	81.4	8.0	10.6	14.1	424	10.2	15.1	28.4	24.6	4.2
	A3B-7	2C	147	41	S	92.8	1.5	5.8	4.5	437	4.1	22.7	43.9	20.4	2.8
Fort Dodge	A4A-1	Ap	11	11	L	39.2	40.6	20.3	0.3	176	1.1	8.0	18.5	8.7	2.9
	A4A-2	A1	51	40	L	37.9	35.4	26.7	0.1	165	0.9	8.3	16.0	9.0	2.9
	A4A-3	A2	76	25	L	43.7	30.2	26.1	0.3	246	4.4	11.4	16.5	11.3	3.2
	A4A-4	2AB	98	22	Gr SL	79.5	6.0	14.6	17.7	666	26.5	23.8	17.8	10.3	2.0
	A4A-5	2BC	131	33	Gr LS	86.7	2.7	10.6	18.8	507	10.0	24.9	37.2	14.6	2.2
	A4A-6	3C	148	17	S	91.2	1.9	6.9	0.3	331	0.9	9.2	49.6	32.4	1.7
Fort Dodge	A5A-1	Ap	19	19	L	28.9	48.0	23.1	0.1	139	0.3	6.3	15.6	6.8	2.4
	A5A-2	A	50	31	L	46.1	31.2	22.7	0.0	207	0.5	9.9	24.7	10.9	3.4
	A5A-3	AB	72	22	SL	57.0	24.4	18.7	0.1	251	1.4	12.0	27.9	13.2	3.9
	A5A-4	2Bw	95	23	SL	70.2	14.8	15.0	3.1	389	7.8	17.4	28.6	14.1	3.7
	A5A-5	2C1	120	25	LS	88.2	5.0	6.8	11.6	469	7.7	20.3	45.1	15.1	2.0
	A5A-6	3C2	138	18	S	91.1	3.0	5.9	2.2	323	1.1	9.1	45.8	33.5	3.1

Table 4. Continued

ID	B.D. (g/cm3)	pH H2O	pH 0.01M KCl	% Calcite	% Dolomite	% Total Carb.	% SOM	% SOC	% Air dry moisture
H1A-1	1.3	5.26	5.09	0.00	0.00	0.00	6.34	4.04	3.0
H1A-2	1.1	5.47	5.34	0.00	0.00	0.00	3.73	2.26	1.8
H1A-3	1.8	4.99	5.06	0.00	0.00	0.00	3.76	2.28	1.5
H2B-1	1.4	5.61	5.50	0.00	1.01	1.01	4.25	2.62	2.1
H2B-2	1.3	6.17	5.95	0.00	0.00	0.00	4.34	2.67	2.8
H2B-3	1.5	6.05	5.78	0.00	0.00	0.00	1.97	1.06	1.8
H2B-4	1.4	6.16	5.85	0.00	0.00	0.00	1.38	0.65	2.0
H2B-5	1.4	6.08	5.74	0.00	0.00	0.00	1.38	0.65	2.9
H2B-6	1.7	6.92	6.76	0.00	0.00	0.00	1.22	0.55	1.9
H4B-1	1.0	5.67	5.47	0.00	0.00	0.00	9.52	6.21	3.6
H4B-2	1.2	6.72	6.43	0.00	0.00	0.00	5.66	3.58	3.3
H4B-3	1.4	7.12	7.04	1.01	1.85	2.86	3.09	1.82	1.5
H5B-1	1.2	6.24	6.07	0.00	0.00	0.00	6.41	4.09	2.7
H5B-2	1.2	5.97	5.97	0.00	0.00	0.00	5.37	3.38	2.4
H5B-3	1.6	5.79	5.72	0.00	0.00	0.00	3.80	2.31	2.0
H5B-4	1.4	6.18	6.20	0.00	0.00	0.00	2.84	1.65	1.4
H5B-5	1.6	7.29	7.42	3.11	22.96	26.07	1.53	0.75	0.7
H6B-1	1.4	4.73	4.57	0.00	0.00	0.00	3.06	1.80	1.2
H6B-2	1.4	5.42	5.32	0.00	0.00	0.00	2.10	1.15	1.1
H6B-3	2.1	6.48	6.64	0.00	5.04	5.04	2.07	1.13	0.8
H7B-1	1.3	4.93	4.75	0.00	0.00	0.00	4.82	3.00	1.7
H7B-2	1.4	5.47	5.28	0.00	0.00	0.00	4.73	2.94	1.8
H8A-1	1.3	4.87	4.72	0.00	0.00	0.00	6.71	4.29	2.9
H8A-2	1.2	5.50	5.22	0.00	0.00	0.00	5.66	3.58	3.1
H8A-3	1.4	6.14	6.07	0.00	2.99	2.99	3.97	2.42	2.4
H8A-4	2.2	7.33	7.38	4.86	17.93	22.79	1.75	0.90	1.0

Table 4. Continued

ID	B.D. (g/cm3)	pH H2O	pH 0.01M KCl	% Calcite	% Dolomite	% Total Carb.	% SOM	% SOC	% Air dry moisture
W1A-1	1.3	6.51	6.35	0.00	1.01	1.01	6.14	3.90	2.2
W1A-2	1.3	6.36	6.08	0.00	0.00	0.00	4.35	2.68	2.6
W1A-3	1.5	6.76	6.61	0.00	0.00	0.00	3.33	1.98	2.3
W1A-4	1.6	6.74	6.55	0.00	0.00	0.00	2.61	1.50	1.9
W1A-5	1.7	7.64	7.51	2.26	13.55	15.81	1.72	0.89	1.2
W1A-6	1.5	7.81	7.62	4.55	18.86	23.40	0.92	0.34	1.0
W2B-1	0.7	5.48	5.44	0.00	0.00	0.00	7.91	5.11	2.2
W2B-2	1.3	5.44	5.29	0.00	0.00	0.00	5.13	3.21	2.4
W2B-3	1.4	6.01	5.83	0.00	0.00	0.00	2.88	1.68	2.0
W2B-4	1.7	7.57	7.44	2.28	16.84	19.13	1.66	0.85	0.9
W3A-1	1.3	6.18	6.02	0.00	0.00	0.00	4.99	3.12	1.8
W3A-2	1.5	6.36	6.14	0.00	0.00	0.00	2.73	1.58	1.4
W3A-3	1.3	7.61	7.49	4.48	16.51	20.99	1.32	0.62	0.8
W3A-4	1.2	7.89	7.81	8.83	22.37	31.20	1.00	0.39	0.6
W3A-5	1.2	7.73	7.52	7.76	17.37	25.13	0.79	0.26	1.0
W4A-1	1.2	5.47	5.19	0.00	0.00	0.00	5.72	3.62	2.8
W4A-2	1.3	5.92	5.57	0.00	0.00	0.00	6.30	4.01	4.3
W4A-3	1.4	6.38	5.96	0.00	0.00	0.00	3.77	2.28	4.3
W4A-4	1.5	6.52	6.03	0.00	0.00	0.00	2.33	1.30	3.2
W4A-5	2.1	6.74	6.27	0.00	0.00	0.00	1.09	0.46	1.9
W5B-1	1.3	5.22	4.93	0.00	0.00	0.00	4.75	2.96	2.5
W5B-2	1.4	5.73	5.28	0.00	0.00	0.00	2.68	1.55	2.7
W5B-3	1.6	6.17	5.70	0.00	0.00	0.00	2.03	1.10	2.6
W5B-4	1.5	6.92	6.66	0.00	3.22	3.22	2.23	1.23	3.1
W5B-5	1.4	8.02	7.70	3.41	13.62	17.03	0.54	0.08	0.8

Table 4. Continued

ID	B.D. (g/cm3)	pH H2O	pH 0.01M KCl	% Calcite	% Dolomite	% Total Carb.	% SOM	% SOC	% Air dry moisture
W6C-1	1.1	5.61	5.41	0.00	0.00	0.00	6.24	3.97	2.6
W6C-2	1.4	5.17	4.88	0.00	0.00	0.00	4.24	2.61	2.6
W6C-3	1.7	5.22	5.01	0.00	0.00	0.00	2.99	1.75	2.7
A1A-1	1.4	5.08	4.90	0.00	0.00	0.00	3.16	1.87	1.7
A1A-2	1.6	4.78	4.58	0.00	0.00	0.00	2.92	1.71	2.2
A1A-3	1.4	5.30	5.11	0.00	0.00	0.00	3.79	2.30	2.6
A1A-4	1.5	5.14	4.93	0.00	0.00	0.00	3.66	2.21	3.4
A1A-5	1.4	4.92	4.70	0.00	0.00	0.00	3.43	2.05	5.0
A1A-6	1.7	5.13	4.79	0.00	0.00	0.00	1.93	1.03	2.8
A1A-7	1.8	5.27	4.94	0.00	0.00	0.00	0.64	0.15	1.1
A2A-1	1.4	5.25	5.14	0.00	0.00	0.00	3.33	1.99	1.4
A2A-2	1.6	4.86	4.64	0.00	0.00	0.00	2.96	1.74	1.8
A2A-3	1.5	4.87	4.65	0.00	0.00	0.00	2.92	1.70	1.7
A2A-4	1.5	5.15	4.84	0.00	0.00	0.00	2.09	1.14	1.6
A2A-5	1.5	5.19	4.85	0.00	0.00	0.00	1.45	0.70	1.6
A2A-6	1.8	5.42	5.02	0.00	0.00	0.00	0.60	0.12	0.8
A3B-1	1.1	4.99	4.85	0.00	0.00	0.00	3.72	2.25	1.5
A3B-2	1.6	4.51	4.34	0.00	0.00	0.00	3.24	1.93	1.6
A3B-3	1.5	4.86	4.69	0.00	0.00	0.00	3.28	1.95	1.5
A3B-4	1.5	5.00	4.77	0.00	0.00	0.00	2.15	1.18	1.4
A3B-5	1.5	5.05	4.76	0.00	0.00	0.00	1.68	0.86	1.2
A3B-6	1.9	5.18	4.87	0.00	0.00	0.00	0.88	0.31	0.7
A3B-7	1.7	5.35	4.97	0.00	0.00	0.00	0.45	0.02	0.5

Table 4. Continued

ID	B.D. (g/cm3)	pH H2O	pH 0.01M KCl	% Calcite	% Dolomite	% Total Carb.	% SOM	% SOC	% Air dry moisture
A4A-1	1.3	5.23	5.16	0.00	0.00	0.00	3.31	1.97	1.5
A4A-2	1.5	4.94	4.79	0.00	0.00	0.00	3.07	1.81	2.3
A4A-3	1.5	5.11	4.91	0.00	0.00	0.00	2.47	1.40	2.4
A4A-4	1.6	5.27	5.01	0.00	0.00	0.00	1.62	0.82	1.7
A4A-5	1.8	5.35	5.08	0.00	0.00	0.00	0.80	0.26	1.0
A4A-6	1.6	5.34	5.06	0.00	0.00	0.00	0.35	0.00	0.3
A5A-1	1.5	4.62	4.50	0.00	0.00	0.00	3.07	1.81	1.5
A5A-2	1.5	5.00	4.82	0.00	0.00	0.00	3.10	1.83	1.5
A5A-3	1.5	5.21	4.99	0.00	0.00	0.00	2.00	1.08	1.4
A5A-4	1.2	5.31	5.06	0.00	0.00	0.00	1.64	0.83	1.3
A5A-5	1.1	5.60	5.27	0.00	0.00	0.00	0.63	0.14	0.5
A5A-6	1.6	5.75	5.31	0.00	0.00	0.00	0.37	0.00	0.5

Table 5. Prevalent morphological features and physical properties of outwash derived soils at the research locations.

Master Horizon	Hallett	Wildin	Avon Lake
A	loam or clay loam 10YR 2/1 mollic colors to about 50cm 1 sbk f to 2 sbk m ρ_b = 1.3g/cm^3 gm = 232µm 24% clay 3% coarse fragments pH 5.6 3.2% SOC many very fine roots	loam to sandy clay loam 10YR 2/1 mollic colors to about 60cm 2 gr f to 2 sbk m ρ_b = 1.3g/cm^3 gm = 318µm 23% clay 5% coarse fragments pH 6.0 2.8% SOC many fine roots	loam 10YR 2/1 or 2/2 or 3/1 mollic colors to about 90cm 1 sbk f or 1 gr f to 2 sbk m ρ_b = 1.5g/cm^3 gm = 181µm 24% clay 0.1% coarse fragments pH 5.0 1.8% SOC common very fine roots
B	gravelly sandy loam 10YR 3/3 to 4/4 cambic subsurface horizon 1 sbk f-m ρ_b = 1.6g/cm^3 gm = 463µm 15% clay 34% coarse fragments pH 6.3 1.4% SOC common very fine roots	gravelly sandy loam 10YR 3/3 or 4/3 cambic subsurface horizon 1 sbk f ρ_b = 1.6g/cm^3 gm = 619µm 15% clay 36% coarse fragments pH 6.8 1.2% SOC many very fine roots	sandy loam to gravelly loamy sand 10YR 3/2 or 3/3 cambic subsurface horizon 1 sbk f-m ρ_b = 1.6g/cm^3 gm = 289µm 21% clay 5% coarse fragments pH 5.2 0.9% SOC few very fine roots
C	gravelly loamy sand 10YR 4/6 or 5/6 0 sgr gm = 503µm 12% clay 36% coarse fragments pH 7.2 0.2% SOC no roots carbonate minerals present *	gravelly sandy loam or gravelly loamy sand 10YR 4/4 or 7.5YR 4/6 to 5/6 0 sgr gm = 695µm 9% clay 36% coarse fragments pH 7.9 0.3% SOC very few very fine roots carbonate minerals present	loamy sand or sand 10YR 4/4 0 sgr gm = 373µm 8% clay 6% coarse fragments pH 5.5 0.1% SOC no roots no carbonate minerals to at least 160cm depth

Terminology: [“sbk” - subangular blocky structure, “gr” – granular structure, “sgr” - single grained (non-structure), “ρ_b” - bulk density, “gm” - geometric mean, “SOC” - soil organic carbon]. * Data for C horizons was lacking at Hallett due to inability to obtain deep cores. Therefore, BC horizon data was utilized to approximate what the prevalent morphological features and physical properties would be.

deemed suitable for the purposes of this study. The soil sampled at Hallett 3 was high in silt and clay amounts but low in sand and coarse fragments. It formed in fine-textured alluvium over outwash with the outwash only occurring in the 2C horizon below 156 cm depth (Table 3 in Appendix A). Sites Hallett 1, 2, and 8 are outwash, but may also have as much as 10 cm of slope wash alluvium or human transported sediment on top (Tables 1,2, &8 in Appendix A). This sediment could have been transported from either the nearby bluff of the till upland or from the bulldozed soil berm on the edge of the Hallett Materials White Pit gravel quarry.

Wildin

Of the six sola sampled at the Wildin location, five were formed in solely outwash. The soil sampled at Wildin 4 is interpreted to have been partially formed in outwash that underlies alluvium (Table 12 in Appendix A). These soils are very sandy and gravelly (Tables 9-14 in Appendix A). These soils were suitable for the purposes of this study.

Jenkins

It was determined that none of the soils sampled at the Jenkins location were derived from outwash (Tables 15 through 20 in Appendix A). These soils, including their C horizons, contain virtually no particles larger than medium sand (Table 4). The parent material is undoubtedly a fluvial deposit; however, the C horizon is lacking coarse sand and is too well sorted to be outwash. The uniformity of the particle size distributions across the entirety of the location suggests river deposited alluvium.

It is easy to understand how the soils and parent material on this particular terrace were misidentified. The landscape position is appropriate for an outwash bench. There has been past gravel quarrying in the immediate vicinity to the northeast and southeast of the field location. Good drainage is present from the dominantly fine to medium sand sediments. There is also an anomalous concentration of pebbles and stones on the surface of the soil. It is hypothesized that these pebbles and stones are either part of a lag deposit or were brought to and concentrated on the surface by frost heave from outwash or till underlying the alluvium. Due to the nature of the parent material occurring at the Jenkins location, these soils could not be used in this study to draw any conclusions about the pedogenesis of outwash derived soils.

Avon Lake

Five cores were collected from a terrace near the small community of Avon Lake southeast of Des Moines, IA. It was determined that all of the five soil cores had outwash materials within them (Tables 21-25 in Appendix A). However, the two easternmost sample sites, Avon Lake 1 and 2 that are slightly downslope and closer to the river, are quite possibly mantled by a thin alluvium deposit approximately 60 to 90 cm thick from either an alluvial fan or the Late Wisconsinan Des Moines River. This is suggested by a lack of coarse sand and pebbles in the upper solum of these two soils (Table 4). There is also a possibility that this mantle is aeolian in origin due to the close proximity of aeolian sand derived soils mapped directly adjacent to the east of the field location.

The soils sampled at the western sites Avon Lake 3, 4, and 5 contained some pebbles and coarse sand in the upper sola and are exclusively formed from outwash sediments.

Bulk Densities

Figures 15 through 18 contain plots of bulk densities from the sola sampled at the Hallett, Wildin and Avon Lake locations. Bulk densities are plotted as a function of depth of the horizons' lower boundaries. In most of the cores analyzed, the lowermost horizons were often very sandy and/or gravelly in texture and therefore not aggregated together well. Many of these lowermost horizons were compacted or highly disturbed during collection with the Giddings soil probe tube. This compaction could have led to higher bulk densities in these horizons. To correct for this problem, all the bulk densities for the lowermost horizons were excluded so as not to skew the results. In Figures 15 through 18, linear trend lines are plotted along with their slopes and R^2 values. The R^2 values do not demonstrate a very strong relationship between bulk density and depth, but a trend is apparent for all locations. Bulk density tends to increase with depth.

The bulk density throughout the whole soil profile for any of the outwash derived soils at time zero (deposition) is assumed to be more or less uniform, but pedogenic processes will have occurred since time zero. The question to be answered is: 'What process or processes have altered the bulk density in the soil profile – particularly the decrease in bulk density in the upper profile?' Bioturbation or the dissolution and leaching of carbonate mineral compounds are the likely processes. Bioturbation is the action of organisms in disturbing soil sediments (e.g. ants burrowing and bringing soil particles from depth to the surface). Removal of carbonates is discussed further in a later section.

The mean and median bulk density of the A horizons is 1.3 g/cm^3 for both Hallett and Wildin whereas Avon Lake has a mean and median both equal to 1.5 g/cm^3 (Table 7). The bulk densities of the B horizons in Table 8 are 1.4 g/cm^3, 1.5 g/cm^3, and 1.6 g/cm^3 for Hallett, Wildin, and Avon Lake respectively. Similarly, comparing the bulk densities of all horizons in Table 6, the values are 1.3 g/cm^3, 1.4 g/cm^3, and 1.5 g/cm^3 for Hallett, Wildin, and Avon Lake, respectively. These values suggest a trend of increasing bulk density across the locations for the master horizons A and B as well as the whole profile in general. However, due to the susceptibility of sandy soils to compact during probing, the limited number of data points due to exclusion of the lowermost horizons, and the similarity of trend lines in Figure 18, it is not plausible to make that assertion. More data and perhaps a better sampling method such as the excavation method is needed.

While not enough to draw a clear trend across the three locations, the mean and median bulk density values in the B horizons still help confirm a starting bulk density at the time of deposition. The values around 1.5 to 1.6 g/cm^3 are suggestive of a time zero bulk density around 1.6 g/cm^3. Presumably this value (or very close to it) would be what was determined in unaltered C horizons had they not been so disturbed during coring. A bulk density of 1.6 g/cm^3 fits well with the bulk density values for outwash listed in Savage et al. (2000). As such, values lower than 1.6 g/cm^3 could likely be due to the previously mentioned pedogenic processes.

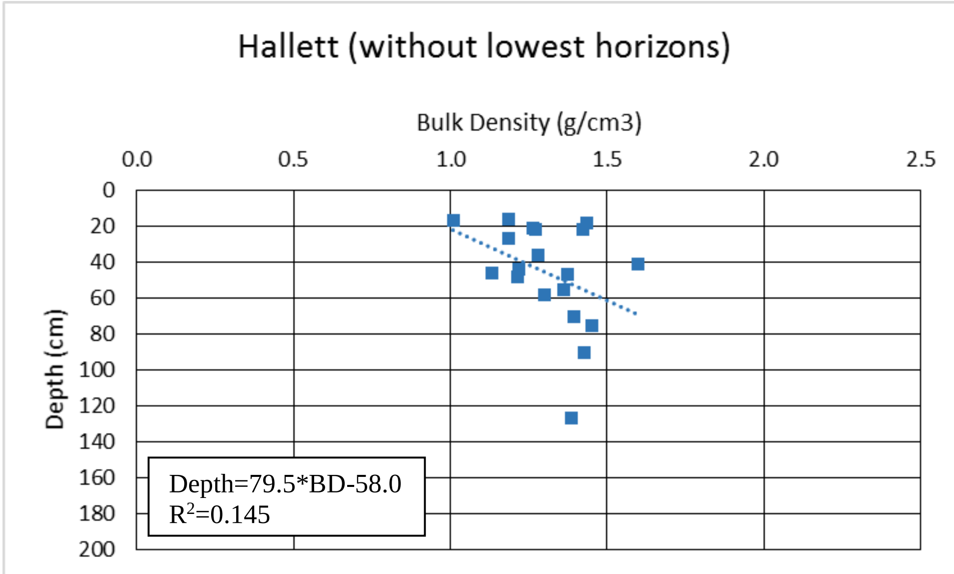

Figure 15. Bulk denisity vs. depth at Hallett. Lowermost horizons are excluded.

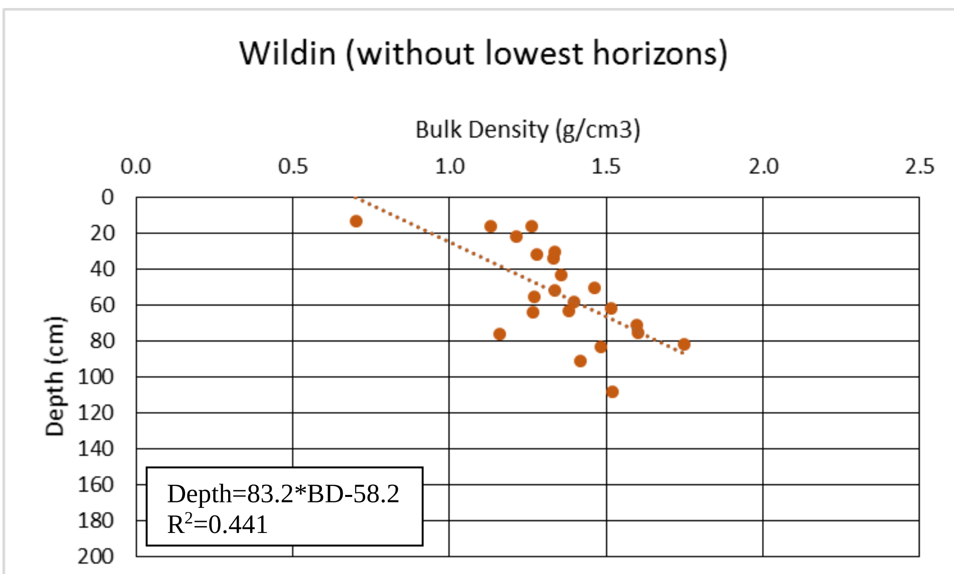

Figure 16. Bulk density vs. depth at Wildin. Lowermost horizons are excluded.

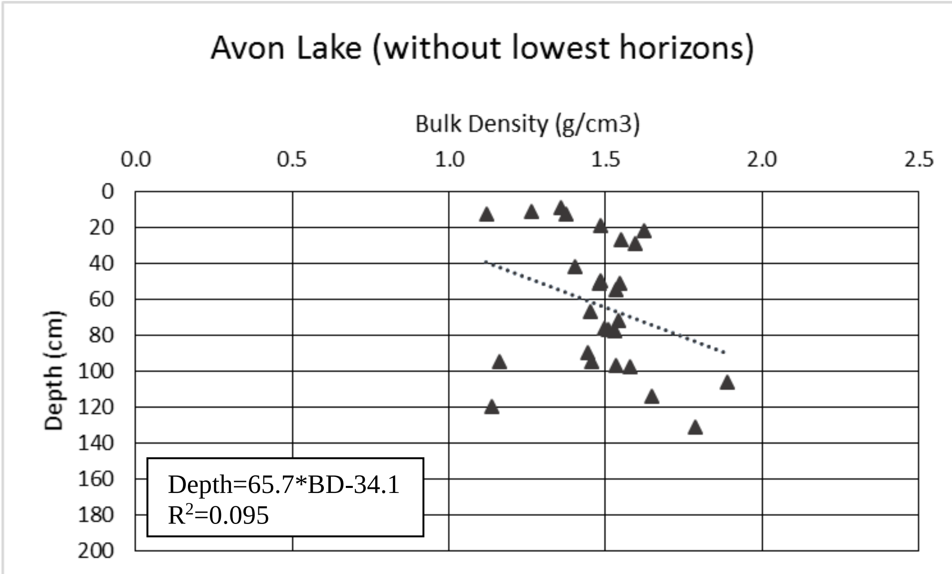

Figure 17. Bulk density vs. depth at Avon Lake. Lowermost horizons are excluded.

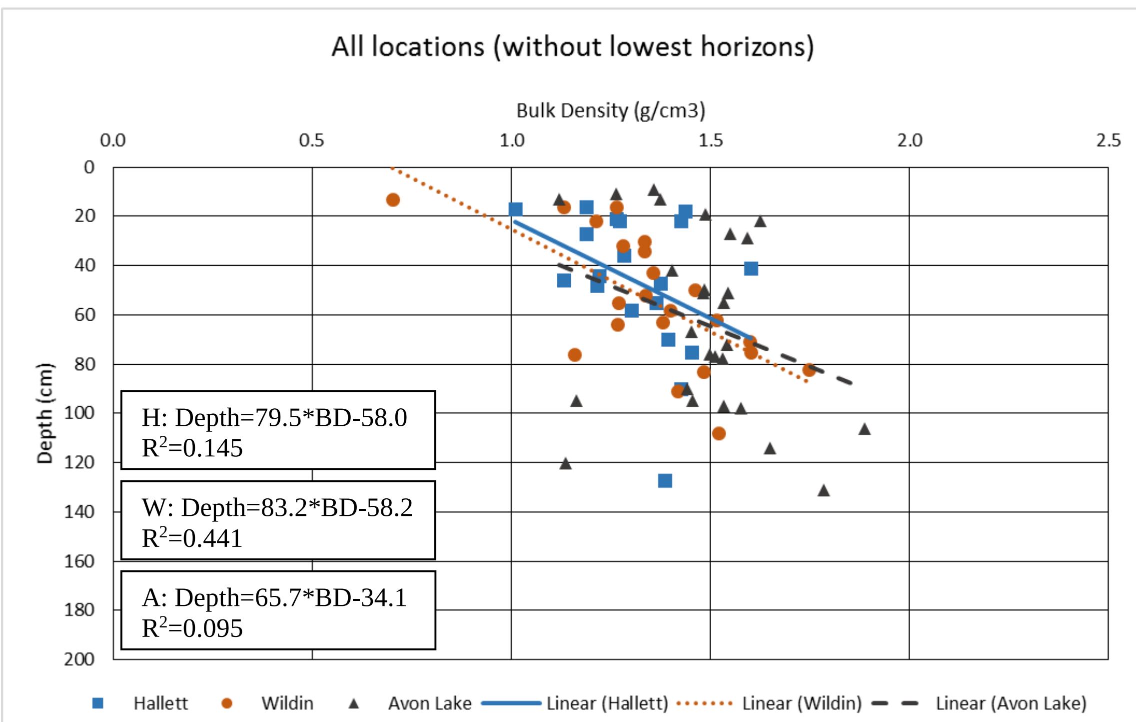

Figure 18. Bulk density vs. depth for all locations. Lowermost horizons are excluded.

Table 6. Descriptive statistics for bulk densities of all horizons excluding the lowermost horizons.

Location	n	Mean	Median	Minimum	Maximum	Standard Deviation
Hallett	19	1.3	1.3	1.0	1.6	0.1
Wildin	22	1.4	1.3	0.7	1.7	0.2
Avon Lake	27	1.5	1.5	1.1	1.9	0.2

Table 7. Descriptive statistics for bulk densities of the A horizons. Excludes the lowermost horizon W4A-5 which is an AC horizon.

Location	n	Mean	Median	Minimum	Maximum	Standard Deviation
Hallett	14	1.3	1.3	1.0	1.6	0.2
Wildin	15	1.3	1.3	0.7	1.5	0.2
Avon Lake	18	1.5	1.5	1.1	1.6	0.1

Table 8. Descriptive statistics for bulk densities of the B horizons. Excludes any lowermost horizons.

Location	n	Mean	Median	Minimum	Maximum	Standard Deviation
Hallett	5	1.4	1.4	1.4	1.4	0.0
Wildin	6	1.5	1.5	1.3	1.7	0.2
Avon Lake	8	1.6	1.5	1.2	1.9	0.2

Table 9. Student's t-test results for bulk density data of all horizons excluding any of the lowermost horizons.

Location	Hallett	Wildin	Avon Lake
Hallett		0.4621	0.0006
Wildin			0.0269
Avon Lake			

Table 10. Student's t-test results for bulk density data of the A horizons. Excludes the lowermost horizon W4A-5 which is an AC horizon.

Location	Hallett	Wildin	Avon Lake
Hallett		0.8574	0.0012
Wildin			0.0072
Avon Lake			

Table 11. Student's t-test results for bulk density data of the B horizons excluding any of the lowermost horizons.

Location	Hallett	Wildin	Avon Lake
Hallett		0.0952	0.0770
Wildin			0.7971
Avon Lake			

Soil Particle Size

Particle size distribution was an integral part to the investigation. Texture and percent mass of coarse fragments were quantified for each sampled soil horizon for all locations. There are numerous ways to display this data and a wealth of information could be attained from the various displays; however, only select charts/figures are presented to support any assertions. Appendix B and Appendix C contain plots showing depth distribution of clay and plots showing geometric means as a function of depth, respectively.

Soil texture and coarse fragments

Soil texture components were quantified and a texture class assigned for each horizon (Table 4). Percent of the fine earth fraction for very coarse, coarse, medium, fine, and very fine sand was also quantified; these are listed in Table 4. The fraction of coarse fragments by weight was also determined as a percent of whole horizon weight; these values are listed in Table 4 as well.

Again, Table 5 shows the prevalent morphological features and physical properties of the A, B, and C master horizons across the three locations. Generally, the A horizons have loam and clay loam textures while the B and C horizons have sandy loam and loamy sand textures. The B and C horizons may be gravelly.

Coarse fragments in the A horizons were generally less than 5% of the total weight (Table 4). Avon Lake had fewer coarse fragments in the A horizons. Coarse fragments comprised around 35% of the soil mass in the B and C horizons at Hallett and Wildin. The B and C horizons at Avon Lake averaged 5% and 6% coarse fragments respectively. Coarse fragment amounts are roughly the same for Hallett and Wildin but drop off significantly at Avon Lake. This drop in coarse fragments even at depth in the C horizons is likely due to the greater distance from the glacial melt source. Ritter et al. (2002) explain that there is a gradual decrease in coarser particles deposited farther and farther from the glacial source.

Geometric means

The geometric mean (or weighted mean particle size) for each horizon was calculated using the data obtained from the different fine earth fractions: clay, silt, very fine sand, fine sand, medium sand, coarse sand, and very coarse sand. Looking at these data with depths, we observe that the upper horizons have smaller geometric means meaning that smaller particles like silt and clay are more prevalent. However, with increasing depth, the geometric mean increases meaning that smaller particles are becoming less and less prevalent. Figures 19 and 20 contain information from the cores Hallett 8A and Avon Lake 3B which exhibit this trend.

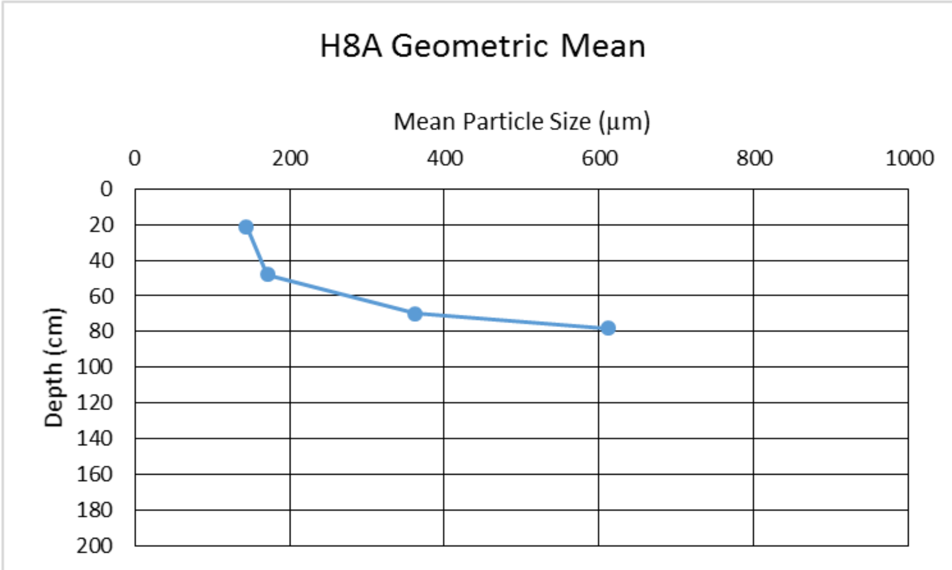

Figure 19. Geometric means vs. depth for each horizon in core H8A.

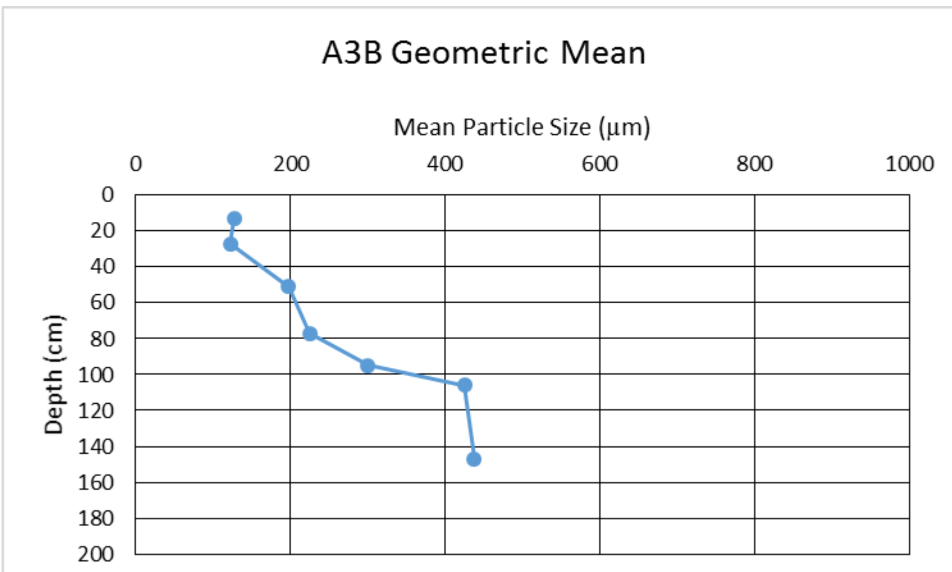

Figure 20. Geometric means vs. depth for each horizon in core A3B.

Some profiles have similar trends to those just mentioned with one distinct difference. In the lowest horizon or two horizons (eg. B, BC, and C) there is a small reversal where the geometric means become smaller (Figures 21 and 22). However, these smaller geometric means at depth were never as small as the geometric means in the surface horizon(s). These “reversals” in the trend of increasing geometric means with increasing depth line up with observed changes in texture in the horizons.

These “reversals” are deposits of outwash dropped out of lower energy water than the deposits directly overlying them. Since these changes in texture occur over fairly narrow intervals, about 20 to 40 cm, it is argued that both groupings are part of the same deposit since there is no observed unconformity. They may have been deposited over the course of a few years or in as little as one day in a dynamic, large flow event.

Outwash streams have excess sediments to transport due to all the debris melting out of the source glacier. During major discharge events, they will be heavily laiden and net depositers. Very coarse sediments deposited on top of coarse sediments could easily be caused by the migration of various interwoven stream channels of the braided outwash stream.

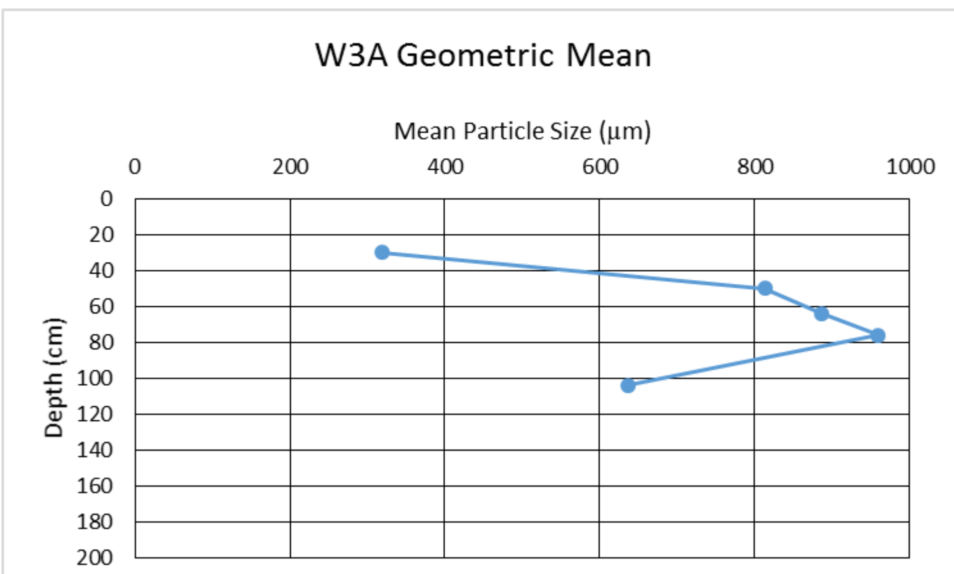

Figure 21. Geometric means vs. depth for each horizon in core W3A.

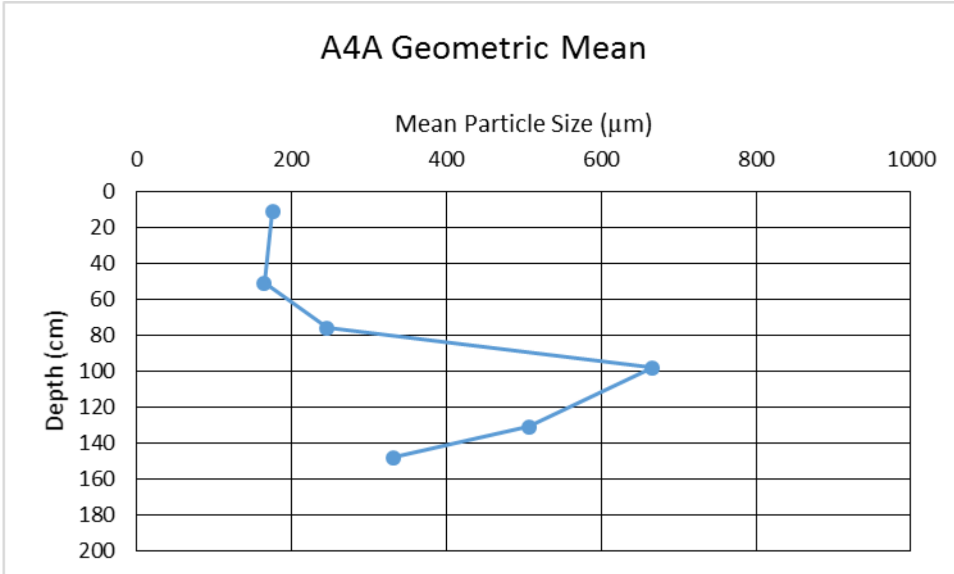

Figure 22. Geometric means vs. depth for each horizon in core A4A.

The surface horizons / upper solum of these soils often have the lowest geometric means. The upper solum of these soils are more loamy containing more silt and clay particles and typically few coarse fragments. One of the questions that this investigation aims to answer is whether these loamy textures occurring at the surface of the soil are a result of lower energy stream flow at the time of parent material deposition, a result of more rapid and intense chemical and physical weathering than previously thought, or perhaps a combination thereof.

Bettis and Hoyer (1986), who investigated many large swaths of the Des Moines River Valley and who described the Late Wisconsinan outwash deposits in detail, interpreted the upper meter or so of material on these outwash terraces (and benches) as “an upper sandy and loamy increment… deposited during waning flow and/or overbank periods following deposition of the middle increment.” Bettis and Hoyer (1986) also mention that this “unit may have been further modified by Holocene aeolian, blow sand activity.”

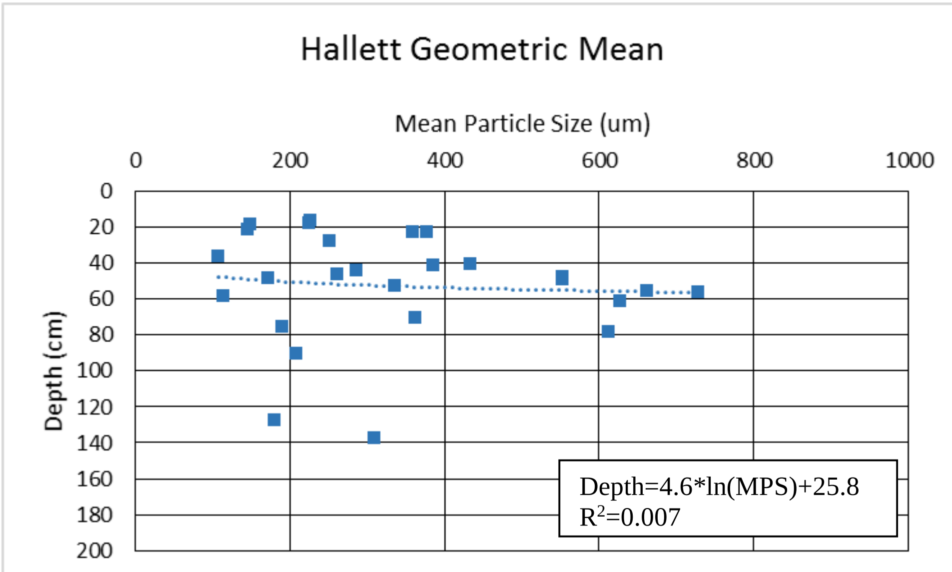

Figure 23. Geometric means vs. depth for each horizon sampled at Hallett excluding site Hallett 3.

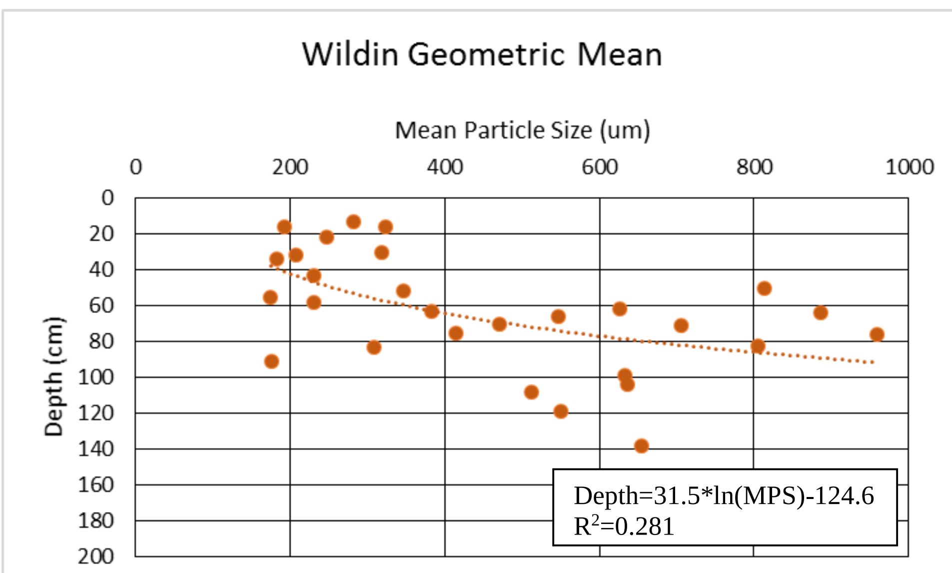

Figure 24. Geometric means vs. depth for each horizon sampled at Wildin.

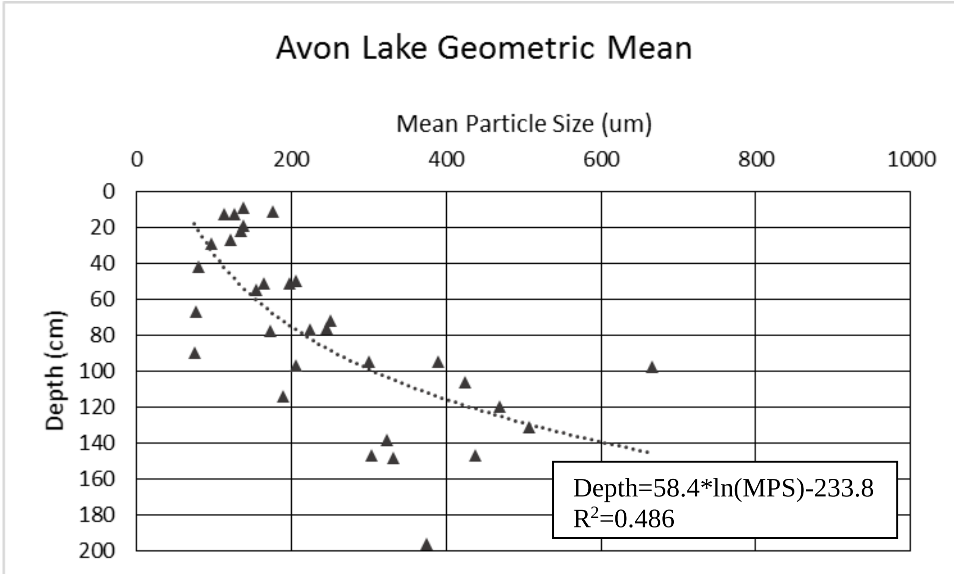

Figure 25. Geometric means vs. depth for each horizon sampled at Avon Lake.

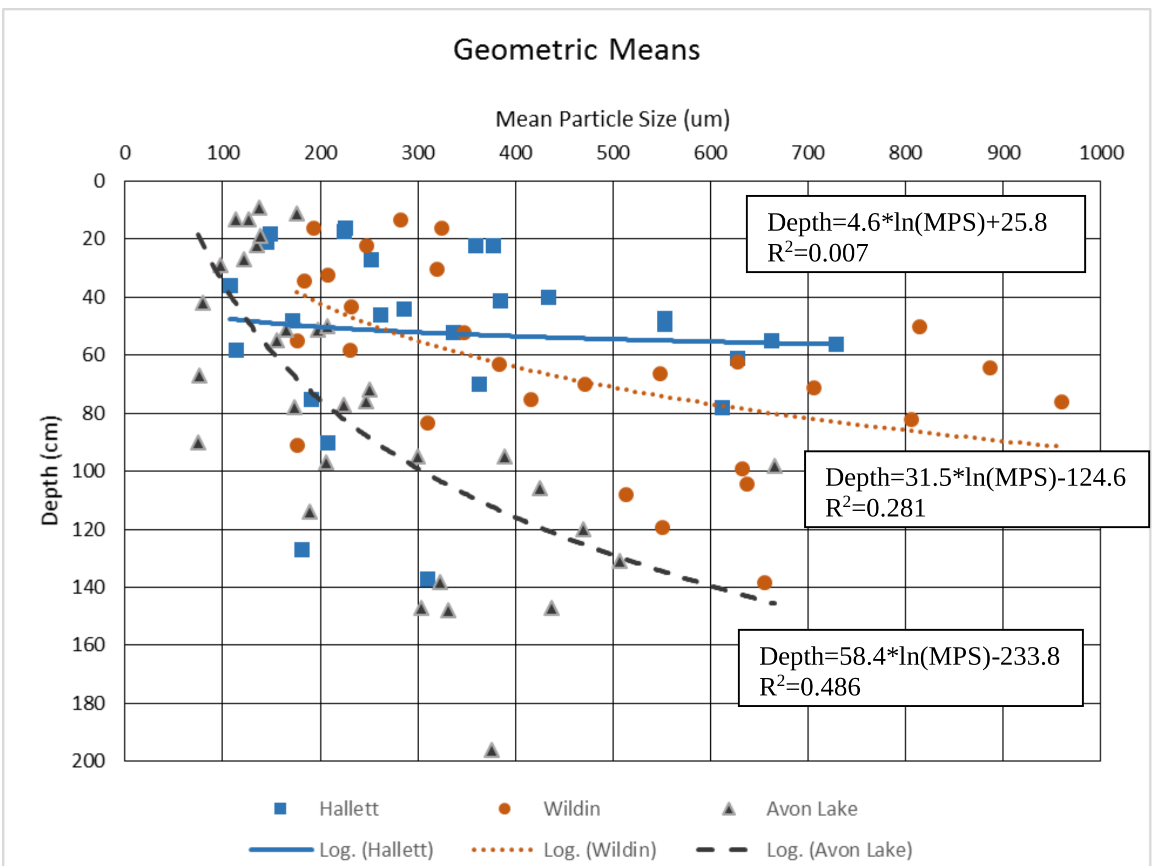

Figure 26. Geometric means vs. depth for all horizons sampled at Hallett, Wildin, and Avon Lake excluding site Hallett 3.

Figures 23 through 25 are graphs of all outwash soils' geometric means for the different locations. Figure 26 shows all geometric means for the three locations plotted on one graph. The groupings are fitted with logarithmic trendlines. The correlation is stronger with decreasing latitude (moving south); ergo the R^2 value for Avon Lake's trendline is better than Wildin's which is better than Hallett's.

Avon Lake has smaller geometric mean values at lower depths. However, Avon Lake is much farther from the source area than the Hallett and Wildin locations. As mentioned briefly in the subsection before this, Ritter et al. (2002) indicates that the farther from the outwash source, the less coarse the deposits will be. Ritter et al. (2002) also mentions, as an extreme example, the outwash terraces of the lower Mississippi River Valley which are so far from the glacial source that some outwash is silty in texture. With the glacial source for the outwash deposited in the DMR valley being located at the Algona moraine or just a little farther north as reported by Bettis and Hoyer (1986), it seems feasible that the outwash deposited a minimum of 200 km from the glacial source would be comprised of slightly finer sediments.

There is another factor that could contribute to this difference. Carbonate minerals were not encountered in any soil cores collected at Avon Lake. The dissolution of calcareous sediments particularly in the sand and coarse fragment fractions could partially explain this difference. Rostad et al. (1976) investigating the "genesis of argillic horizons in soils derived from coarse-textured calcareous gravels," found, among other things, that through the dissolution of calcareous sands and gravels, clay sized impurities are released and increase the number of clay particles. So essentially there are two ways that the texture is being altered; the number of sand particles is decreasing simultaneously while the number of clay particles is increasing. Rostad et al. (1976) found argillic horizons with 24-50% clay that developed from calcareous, gravelly deposits containing less than 10% clay. They claim that approximately half of the clay present in their B horizons could be accounted for as a result of carbonate dissolution and leaching.

In U.S. Geological Survey (1958), the pebble fraction of Tazewell drift was examined and found to be comprised of 33% limestone as shown in Table 1. Identified outwash from the C horizons of this study contain up to 65.6% coarse fragments and up to 92.8% sand in the fine earth fraction. If the conservative assumption is that calcareous sediments represent approximately 25% of the coarse fragments and approximately 25% of the sand fraction, it is suggestive that the dissolution and leaching of carbonates in these soils would lead to similar outcomes to those in Rostad et al. (1976). However, the transformation of the textures would be subdued, because the two pairs of study sites in Rostad et al. (1976) contained soils formed in calcareous gravel comprised of 40% and 60% carbonates ("One member of each pair occurred on a terrace whereas the other occurred on a kame.")

The descriptive statistics for the geometric means of the different locations in Tables 12 through 14 do not seem to show any identifiable trends; this may be due to the dynamics of outwash deposition. Corresponding Student t-test values for the data are displayed in Tables 15 through 17.

Table 12. Descriptive statistics for geometric means for all horizons.

Location	n	Mean	Median	Minimum	Maximum	Standard Deviation
Hallett	26	338.66	297.28	107.84	727.90	182.48
Wildin	28	458.01	399.11	175.34	959.56	237.14
Avon Lake	32	244.40	201.94	75.19	665.94	144.03

Table 13. Descriptive statistics for geometric means for the A horizons.

Location	n	Mean	Median	Minimum	Maximum	Standard Deviation
Hallett	14	231.69	225.08	107.84	384.64	93.74
Wildin	16	318.30	264.50	175.34	654.49	154.88
Avon Lake	18	181.44	146.94	76.61	665.94	130.83

Table 14. Descriptive statistics for geometric means for the B horizons.

Location	n	Mean	Median	Minimum	Maximum	Standard Deviation
Hallett	12	463.46	492.94	180.14	727.90	183.67
Wildin	8	619.01	626.41	309.01	886.18	212.56
Avon Lake	8	289.44	262.40	75.19	506.57	142.69

Table 15. Student's t-test results for geometric means of all horizons.

Location	Hallett	Wildin	Avon Lake
Hallett		0.0425	0.0370
Wildin			0.0002
Avon Lake			

Table 16. Student's t-test results for geometric means of the A horizons.

Location	Hallett	Wildin	Avon Lake
Hallett		0.0720	0.2158
Wildin			0.0097
Avon Lake			

Table 17. Student's t-test results for geometric means of the B horizons.

Location	Hallett	Wildin	Avon Lake
Hallett		0.1136	0.0291
Wildin			0.0033
Avon Lake			

Clay distributions

Clay contents of each soil horizon were determined using the pipette method. Amounts of clay varied in the outwash soil profiles, but were typically below 30% of the fine earth fraction. Mean and median values for clay content when comparing all horizons, only the A horizons, or only the B horizons across the research locations hardly differ (Tables 18-20). The mean clay percentage in the B horizons at Avon Lake is about 5% higher than the B horizons of Hallett and Wildin. However, they were not significantly different (Table 23).

When clay percentage is plotted against depth (of the horizon lower boundary), the trends are almost inverse to the previously discussed geometric mean trends (Figures 19-22). Figures 27 through 30 show the clay distributions corresponding to the geometric means of the four profiles displayed in the previous subsection. These plotted trends are clearly related, however, the t-test values for clay percentages (Tables 21-23) were much higher than those for the geometric mean values (Tables 15-17).

In this study, there were only three argillic horizons described within profiles of the outwash derived soils. Hallett, Wildin, and Avon Lake each had one sampled outwash derived soil containing an argillic horizon found at sites Hallett 2, Wildin 5, and Avon Lake 1. These soils' respective clay distributions, as expected, are different from the other sampled sola. These and all other clay plots are available in Appendix B.

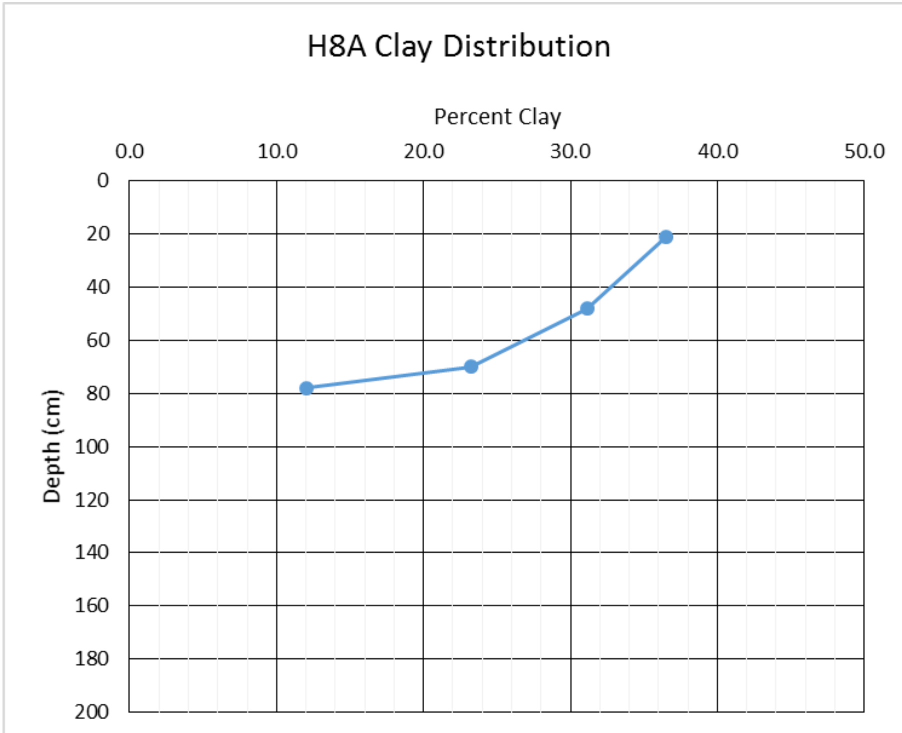

Figure 27. Percent clay vs. depth for each horizon in core H8A.

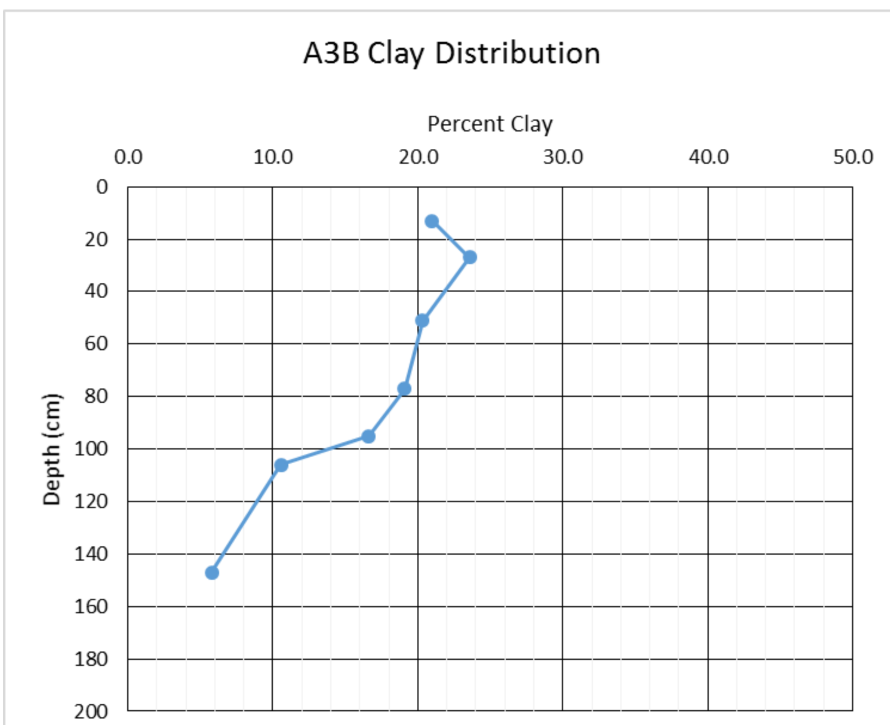

Figure 28. Percent clay vs. depth for each horizon in core A3B.

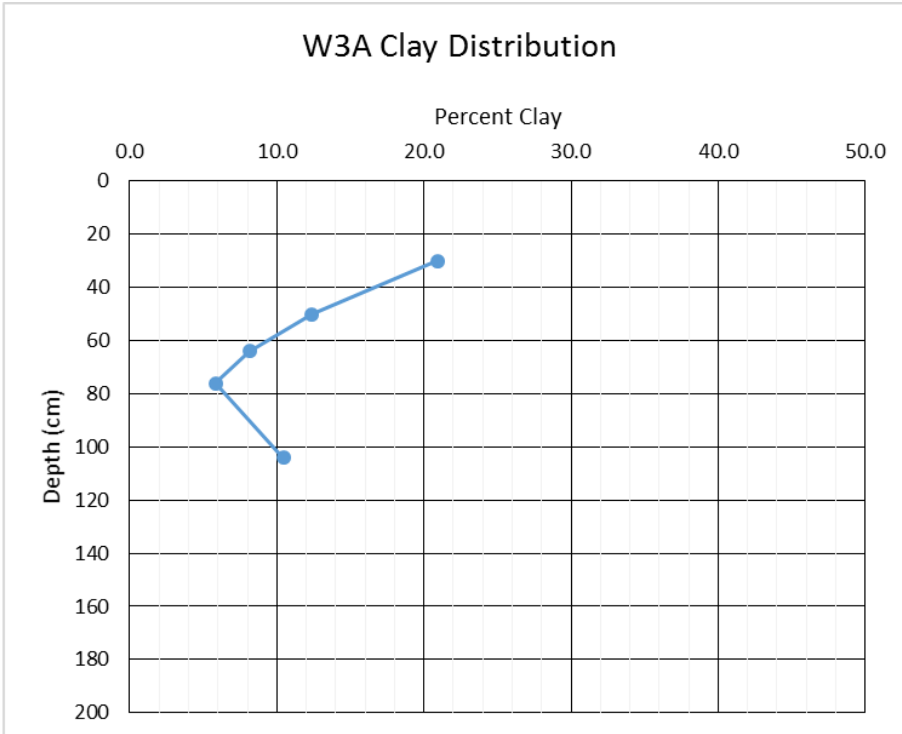

Figure 29. Percent clay vs. depth for each horizon in core W3A.

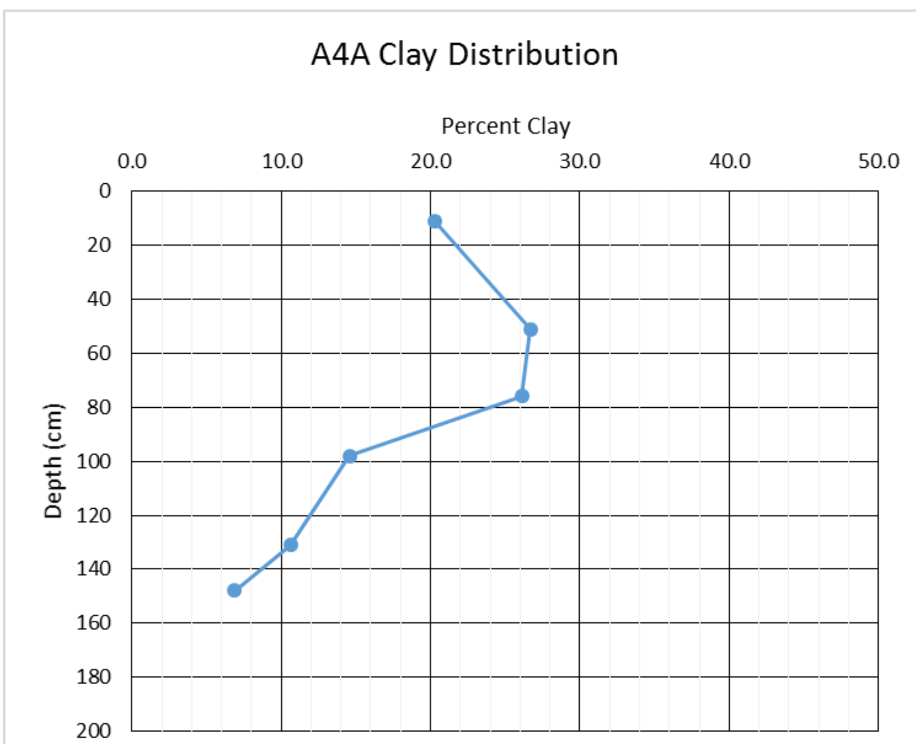

Figure 30. Percent clay vs. depth for each horizon in core A4A.

Table 18. Descriptive statistics for percent clay for all horizons.

Location	n	Mean	Median	Minimum	Maximum	Standard Deviation
Hallett	26	20.11	20.54	6.24	36.54	7.49
Wildin	28	18.93	20.99	5.82	32.29	7.19
Avon Lake	32	19.88	20.62	5.77	48.36	9.41

Table 19. Descriptive statistics for percent clay for the A horizons.

Location	n	Mean	Median	Minimum	Maximum	Standard Deviation
Hallett	14	24.14	23.56	14.86	36.54	5.89
Wildin	16	23.25	23.12	15.62	32.29	4.02
Avon Lake	18	23.60	22.40	14.57	38.04	5.33

Table 20. Descriptive statistics for percent clay for the B horizons.

Location	n	Mean	Median	Minimum	Maximum	Standard Deviation
Hallett	12	15.41	13.97	6.24	26.14	6.48
Wildin	8	15.38	13.44	8.15	27.95	6.85
Avon Lake	8	20.75	17.29	10.57	48.36	12.42

Table 21. Student's t-Test results for percent clay values for all horizons.

Location	Hallett	Wildin	Avon Lake
Hallett		0.5586	0.9181
Wildin			0.6603
Avon Lake			

Table 22. Student's t-Test results for percent clay values for the A horizons.

Location	Hallett	Wildin	Avon Lake
Hallett		0.6381	0.7910
Wildin			0.8285
Avon Lake			

Table 23. Student's t-Test results for percent clay values for the B horizons.

Location	Hallett	Wildin	Avon Lake
Hallett		0.9913	0.2907
Wildin			0.3073
Avon Lake			

Soil pH in H_2O and 0.01 M KCl

Soil pH was measured in deionized water and in 0.01 molar KCl. Soil pH was determined for each soil horizon of the collected cores from all locations. The pH values varied greatly across the sample sites of all the locations (Table 4). Soil pH is partially controlled by mineralogy, vegetation, and land management. Soil pH can and will change over time and space due to soil processes (Schaetzl and Anderson 2005).

Soil pH measured in deionized water was very similar to pH measured in 0.01 molar KCl (Table 4) and therefore only findings for pH measured in water is presented here. Plots of soil pH in 0.01 molar KCl are listed in Appendix F. The distribution of pH with depth exhibited primarily two trends. The pH simply increases in a linear or curve-linear trend with depth as shown in soil core W4A (Figure 31). In the other trend, pH decreases slightly below the surface horizon(s), then gradually increases in a linear or curve-linear trend with depth as demonstrated in W1A seen in Figure 32.

The higher pH, observed above the slight dip or decrease in pH before subsequent increase with depth (e.g. Wildin 1A), is interpreted to be the result of agricultural lime amendments incorporated into the surface horizon(s) to maintain or raise soil pH to suitable levels for crop growth. This is supported by evidence in the profile descriptions. Profiles W3A, J3B, and J4A each contained one or two isolated carbonate coarse fragments in their uppermost horizon.

Comparing all the data (Tables 24-26), mean and median pH values for whole cores, A horizons, and B horizons were highest for the Wildin location followed by Hallett followed by Avon Lake. As seen in Figures 33 through 36, when examining all outwash soils together at each location, there is a linear increase in pH with depth. The slope and y-intercept for Hallett and Wildin are virtually identical. Avon Lake however is far more steeply sloping and has a different y-intercept.

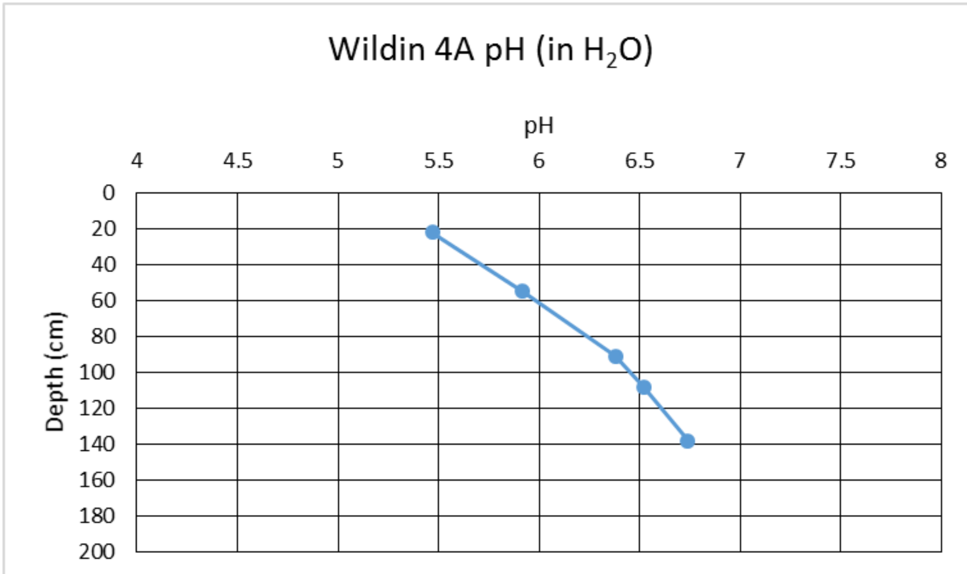

Figure 31. pH in H_2O vs. depth for each horizon in core W4A.

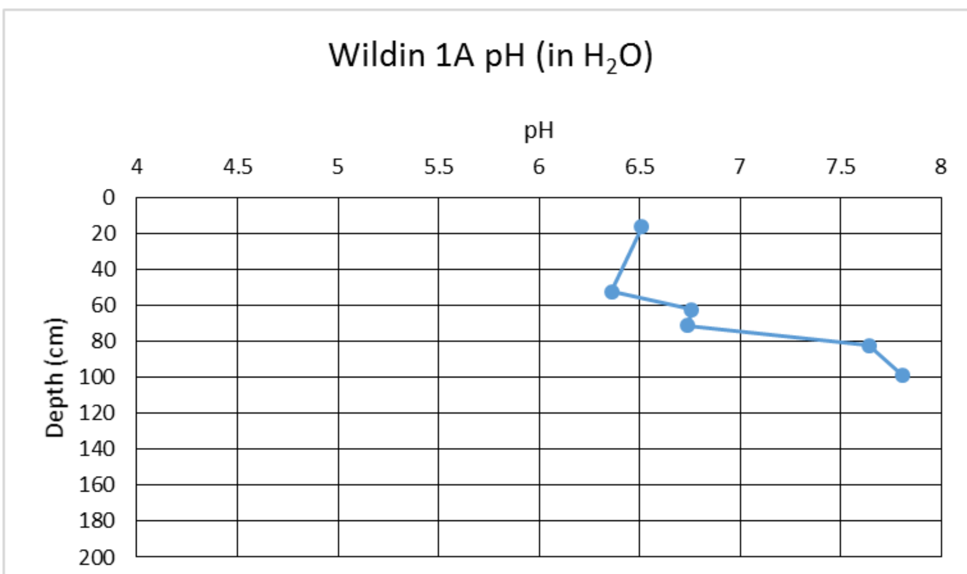

Figure 32. pH in H_2O vs. depth for each horizon in core W1A.

It is not plausible to interpret a trend in soil pH as it relates to location with the data collected. The mean and median values do not support a trend. Even when comparing just soil horizons with lower boundaries occurring between the depth interval from 40 cm to 80 cm, there is no clear trend as can be seen in Table 30. Legacy of land/soil management as it affects soil pH is too great to declare any clear trends in pH as they relate to location in this study. Deeper cores that would capture the C horizons at Hallett or more sampled locations across the state could allow for observance a trend, however.

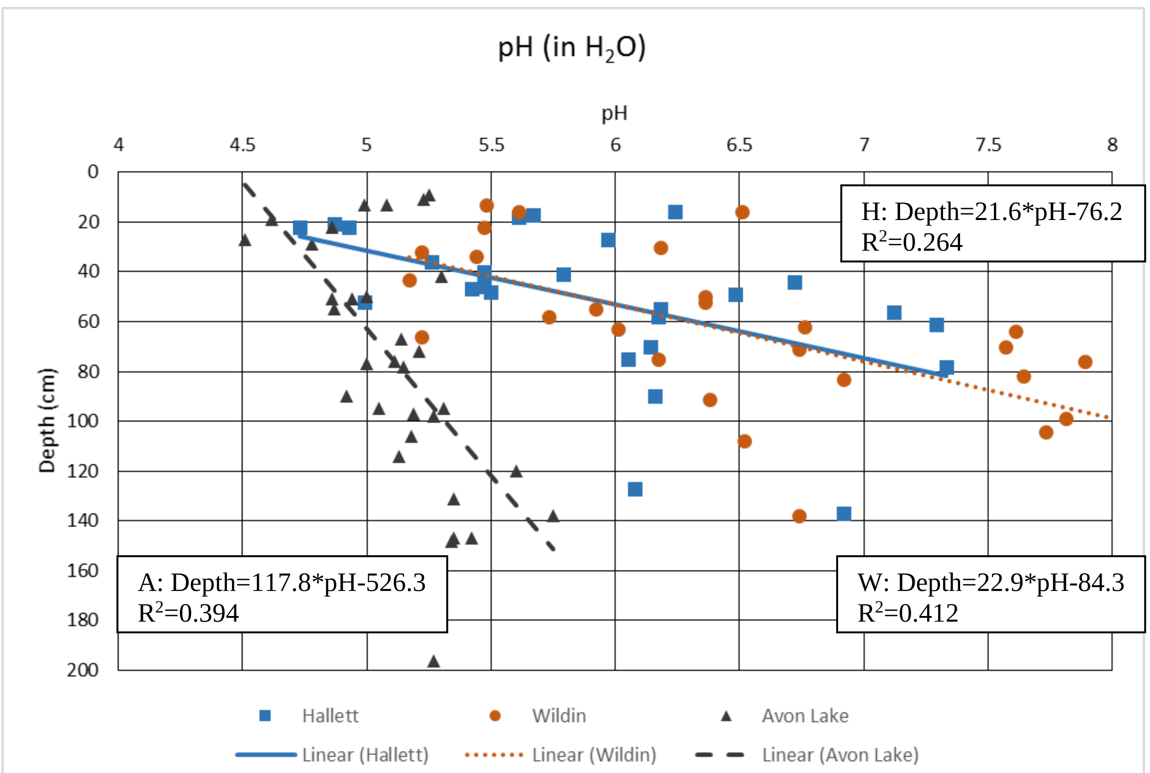

Figure 33. pH in H_2O vs. depth for all horizons at all locations.

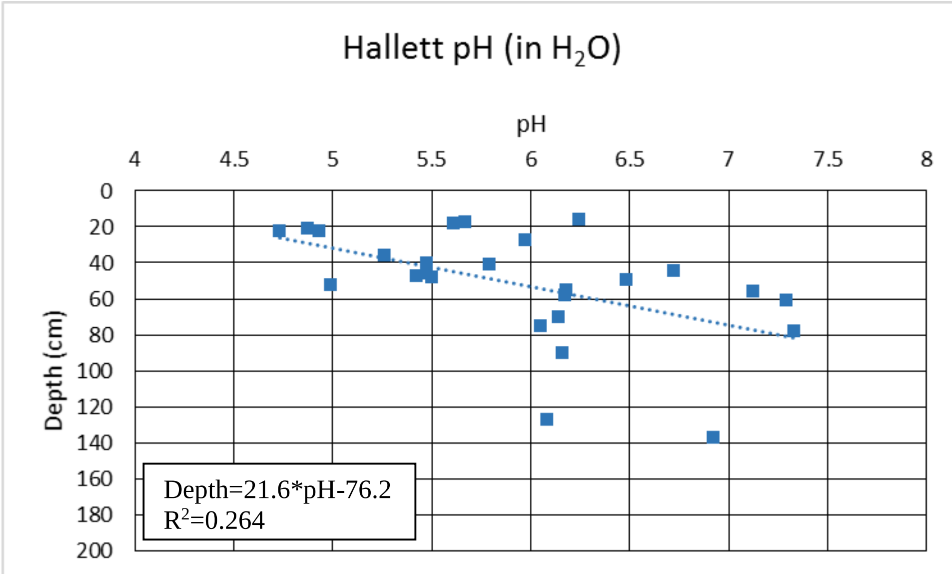

Figure 34. pH in H_2O vs. depth for all horizons at Hallett.

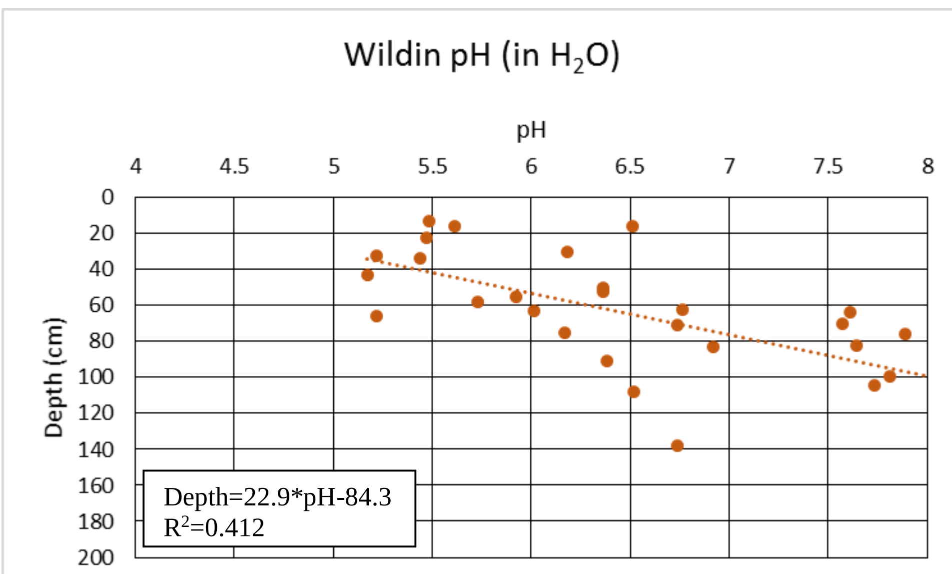

Figure 35. pH in H_2O vs. depth for all horizons at Wildin.

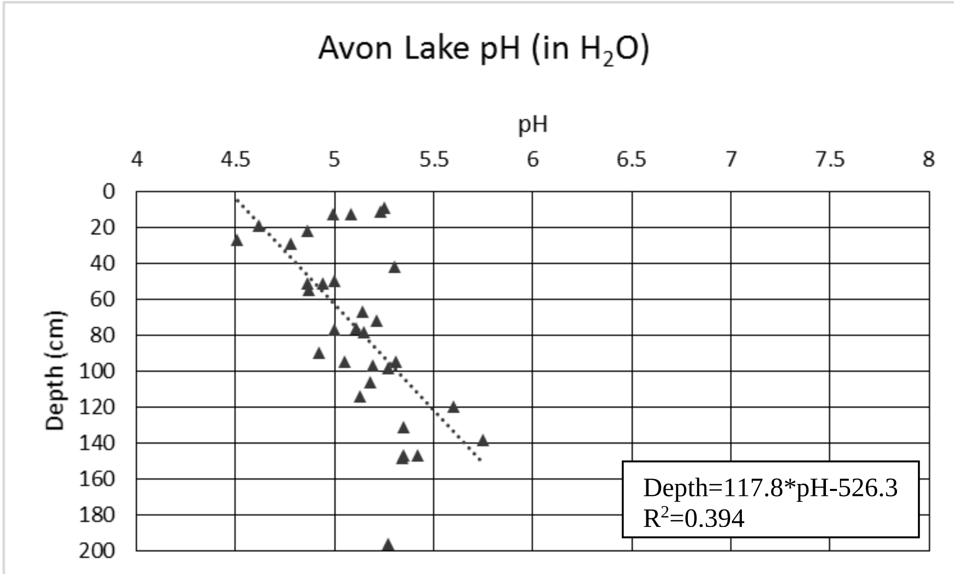

Figure 36. pH in H_2O vs. depth for all horizons at Avon Lake.

Table 24. Descriptive statistics for pH in H_2O for all horizons.

Location	n	Mean	Median	Minimum	Maximum	Standard Deviation
Hallett	26	5.94	6.01	4.73	7.33	0.73
Wildin	28	6.47	6.37	5.17	8.02	0.90
Avon Lake	32	5.13	5.15	4.51	5.75	0.26

Table 25. Descriptive statistics for pH in H_2O for the A horizons.

Location	n	Mean	Median	Minimum	Maximum	Standard Deviation
Hallett	14	5.64	5.64	4.73	6.72	0.57
Wildin	16	5.97	5.97	5.17	6.76	0.54
Avon Lake	18	5.01	5.04	4.51	5.30	0.23

Table 26. Descriptive statistics for pH in H_2O for the B horizons.

Location	n	Mean	Median	Minimum	Maximum	Standard Deviation
Hallett	12	6.30	6.17	4.99	7.33	0.76
Wildin	8	6.78	6.83	5.22	7.64	0.85
Avon Lake	8	5.14	5.16	4.92	5.35	0.15

Table 27. Student's t-test results for pH in H_2O for all horizons.

Location	Hallett	Wildin	Avon Lake
Hallett		0.0222	0.0000
Wildin			0.0000
Avon Lake			

Table 28. Student's t-test results for pH in H_2O for the A horizons.

Location	Hallett	Wildin	Avon Lake
Hallett		0.1189	0.0012
Wildin			0.0000
Avon Lake			

Table 29. Student's t-test results for pH in H_2O for the B horizons.

Location	Hallett	Wildin	Avon Lake
Hallett		0.2183	0.0002
Wildin			0.0009
Avon Lake			

Table 30. Mean pH in H_2O for horizons with lower boundaries within the range of 40 to 80 cm depth below the surface.

Location	Mean
Hallett	6.14
Wildin	6.42
Avon Lake	5.06

Soil Organic Carbon

Soil organic carbon (SOC) was measured for each horizon of each core analyzed. As shown in Tables 31 through 33, mean and median percent SOC values show a trend where SOC decreases with decreasing latitude (with Hallett being the northernmost location and Avon Lake being the southernmost location). Ignoring the Jenkins data (because it is not outwash), this trend exists in the mean and median values when comparing all horizons, only the A horizons, and only the B horizons. This could be due to the increase of MAP and MAT across Iowa from the northwest to the southeast. Tables 34 through 36 are t-test values for the aforementioned groupings.

To control for any effects of varying bulk density. SOC stocks were calculated and compared as well for the first 9 cm of the A horizons. 9 cm was selected due to that number being the thinnest horizon recorded during the profile description phase. The same trend appears when comparing these SOC stock values (Mg/ha) as seen in Table 37. Table 38 displays the t-test values for the SOC stock populations.

Figures 37 and 38 are plots of percent SOC versus depth (of horizon’s lower boundary) for all the horizons separated into different populations by location. Figure 37 shows the data fitted with linear trend lines; Figure 38 shows the data fitted with exponential trend lines. Both figures show a trend of decreasing SOC in the upper solum as latitude decreases and SOC in the lower solum increasing with decreasing latitude. Higher percentages of SOC in lower solum at the lower latitudes suggest greater/deeper soil development.

Figures 39 through 41 are simply the individual location plots of percent SOC versus depth for each horizon. SOC tends to decrease with depth in a linear or curve-linear way.

Table 31. Descriptive statistics for SOC for all horizons.

Location	n	Mean	Median	Minimum	Maximum	Standard Deviation
Hallett	26	2.38	2.29	0.55	6.21	1.40
Wildin	28	1.97	1.63	0.08	5.11	1.36
Avon Lake	32	1.22	1.29	0.00	2.30	0.78

Table 32. Descriptive statistics for SOC for the A horizons.

Location	n	Mean	Median	Minimum	Maximum	Standard Deviation
Hallett	14	3.21	3.19	1.06	6.21	1.27
Wildin	16	2.78	2.82	0.46	5.11	1.21
Avon Lake	18	1.75	1.82	0.82	2.30	0.41

Table 33. Descriptive statistics for SOC for the B horizons.

Location	n	Mean	Median	Minimum	Maximum	Standard Deviation
Hallett	12	1.41	1.14	0.55	2.94	0.80
Wildin	8	1.19	1.16	0.62	1.75	0.40
Avon Lake	8	0.90	0.84	0.26	2.05	0.56

Table 34. Student's t-test results for percent SOC for all horizons.

Location	Hallett	Wildin	Avon Lake
Hallett		0.2795	0.0006
Wildin			0.0148
Avon Lake			

Table 35. Student's t-test results for percent SOC for the A horizons.

Location	Hallett	Wildin	Avon Lake
Hallett		0.3551	0.0009
Wildin			0.0045
Avon Lake			

Table 36. Student's t-test results for percent SOC for the B horizons.

Location	Hallett	Wildin	Avon Lake
Hallett		0.4280	0.1160
Wildin			0.2647
Avon Lake			

Table 37. Descriptive statistics for SOC stocks in 9 cm thick A horizons. Units of Mg/ha.

Location	n	Mean	Median	Minimum	Maximum	Standard Deviation
Hallett	7	40.97	43.69	23.08	56.40	11.20
Wildin	6	38.00	38.45	32.26	44.35	4.41
Avon Lake	5	23.35	23.15	22.39	24.27	0.87

Table 38. Student's t-test results for SOC stocks in 9 cm thick A horizons.

Location	Hallett	Wildin	Avon Lake
Hallett		0.5361	0.0058
Wildin			0.0003
Avon Lake			

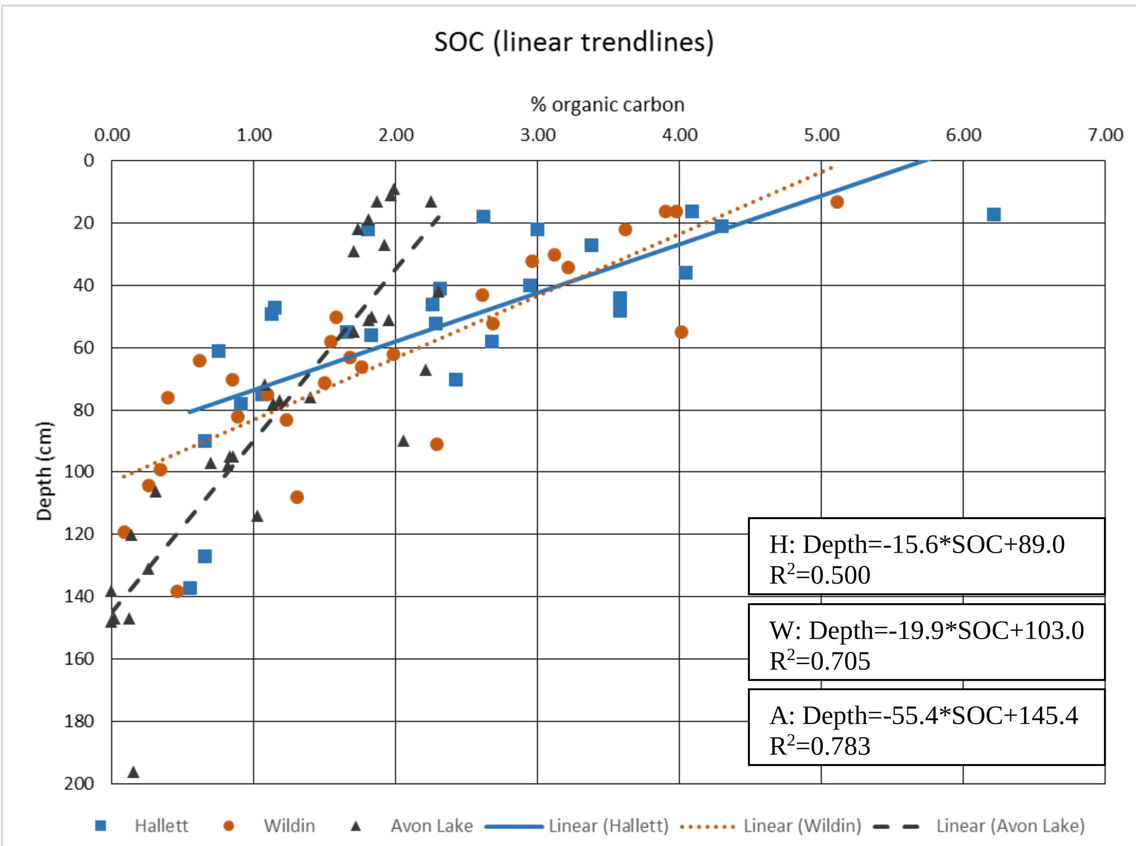

Figure 37. Percent SOC vs. depth for all horizons with linear trend lines.

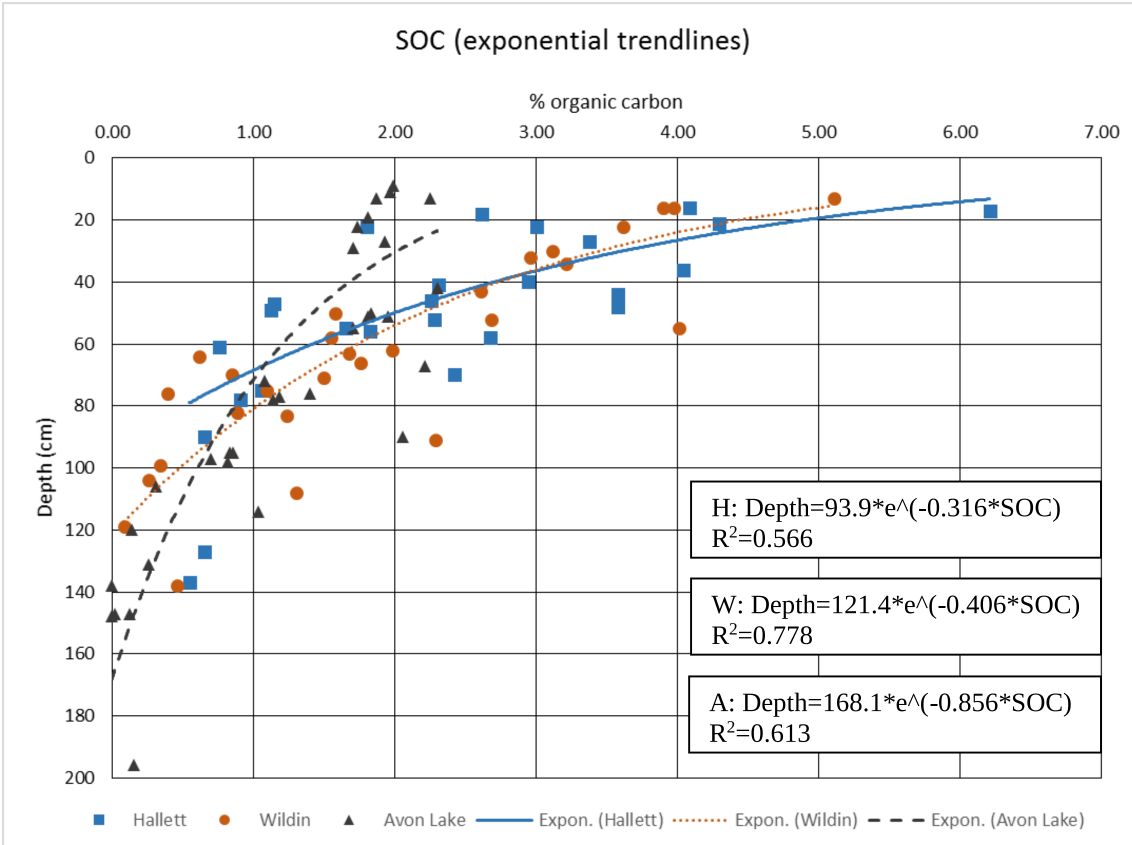

Figure 38. Percent SOC vs. depth for all horizons with exponential trend lines.

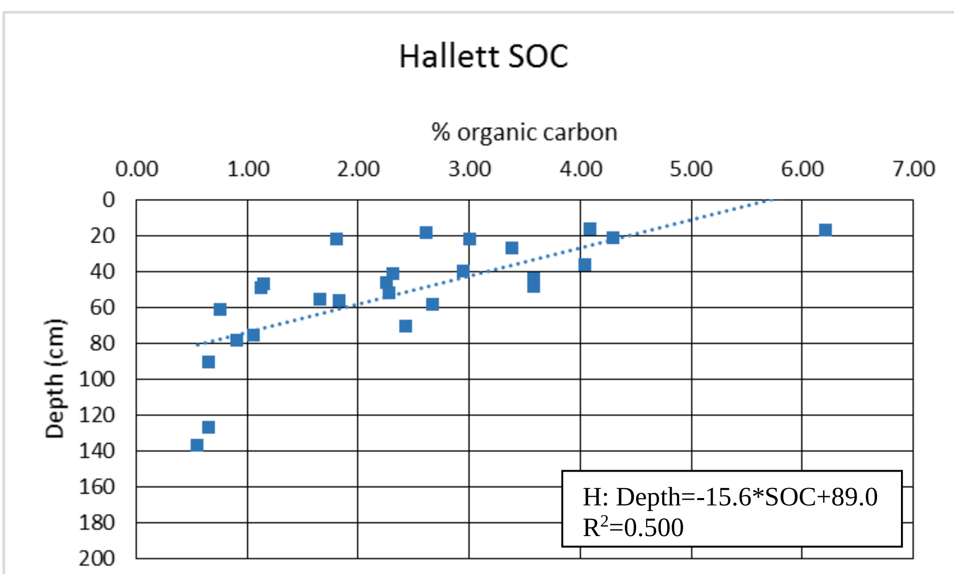

Figure 39. Percent SOC vs. depth for each horizon at Hallett.

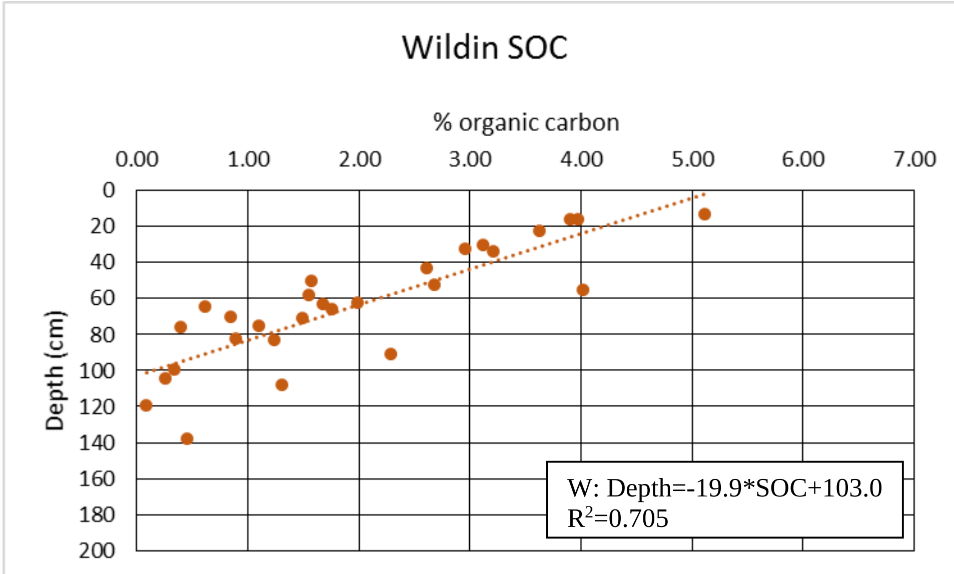

Figure 40. Percent SOC vs. depth for each horizon at Wildin.

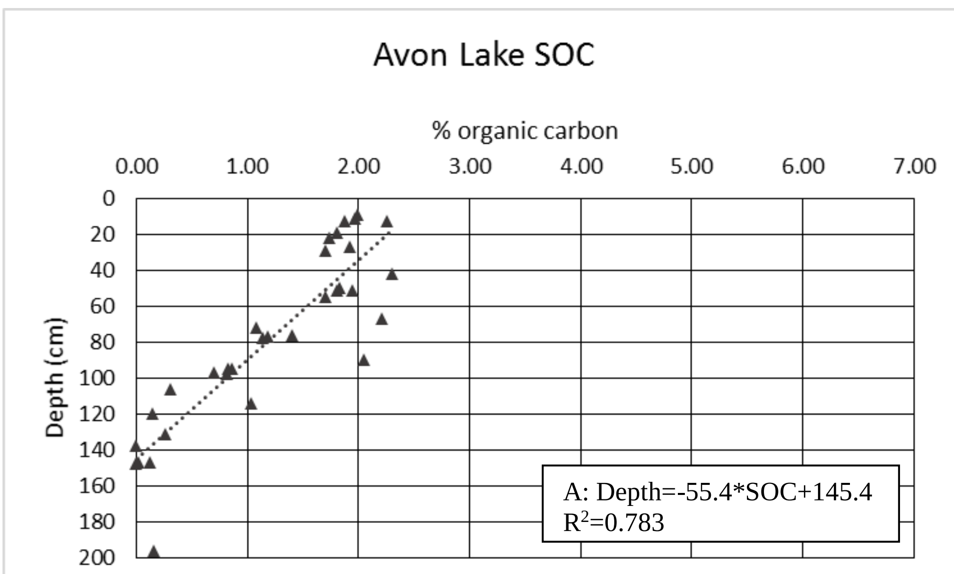

Figure 41. Percent SOC vs. depth for each horizon at Avon Lake.

Inorganic Carbon

Percent calcite and dolomite data are presented in Table 4. Carbonate minerals were only detected in a portion of the cores at the Hallett and Wildin locations. No carbonates were found in soils collected at the Avon Lake location. However, if cores were taken to greater depths, there would likely be carbonate minerals present.

Carbonates were identified in primarily the BC and C horizons at Hallett and Wildin (Tables 1-2, 4-14 in Appendix A). However, not every site could be cored to a depth adequate enough to encounter the BC and/or C horizons. This was usually due to the Giddings Probe encountering enough gravel that forcibly stopped its penetration.

In this study, two soil cores were always collected about 40 cm apart at each sampling site yielding two companion cores (e.g. H1A and H1B). All of these companion cores were treated identically for all intents and purposes, but a discrepancy was observed between cores H2A and H2B. At an equivalent depth, there were carbonates present in only H2A even though the cores were only horizontally separated by approximately 40 cm. These carbonates, however, were only present as large pebbles (5-10 mm in diameter). All other soil properties appeared to be the same. This exhibits surprising spatial variability in the distribution of carbonate minerals within the solum and across the landscape. This one discrepancy may just be the result of random chance that a few more very coarse limestone fragments were deposited in this one spot, but it does help demonstrate the spatially variable nature of outwash mineralogy.

It can be assumed that most of the calcareous sediments are sourced from limestone/dolostone (sedimentary) rock present in the states north of Iowa (i.e. Minnesota, North Dakota, South Dakota). This is evidenced by the Pierre shale

Table 39. Percent calcite and dolomite of the fine earth fraction in horizons found to contain carbonate minerals.

Sample ID	% Calcite	% Dolomite	%Total Carbonates	Horizon
H2B-1	0.00	1.01	1.01	Ap
H4B-3	1.01	1.85	2.86	2BC
H5B-5	3.11	22.96	26.07	2BC
H6B-3	0.00	5.04	5.04	2Bw2
H8A-3	0.00	2.99	2.99	2Bw
H8A-4	4.86	17.93	22.79	2BC
W1A-1	0.00	1.01	1.01	A1
W1A-5	2.26	13.55	15.81	2BC
W1A-6	4.55	18.86	23.40	2C
W2B-4	2.28	16.84	19.13	2BC
W3A-3	4.48	16.51	20.99	2BC
W3A-4	8.83	22.37	31.20	2C1
W3A-5	7.76	17.37	25.13	2C2
W5B-4	0.00	3.22	3.22	2Bt
W5B-5	3.41	13.62	17.03	2C

concretions found in the outwash deposit described in Table 1. The two dominant carbonate minerals in these limestone fragments contained within the Noah Creek outwash were calcite and dolomite with the latter being far more prevalent. Other carbonate minerals were considered negligible.

Table 39 shows the soil horizon samples within this study that contained measurable amounts of carbonate minerals. There were two surface horizons H2B-1 and W1A-1 (Table 39) that showed trace amounts of carbonates, but these also had acidic pH values. If the measurements for H2B-1 and W1A-1 were accurate, these carbonates are likely few coarse particle remnants of agricultural lime applications to remediate soil pH. The underlying few horizons contained no carbonates.

All other soil horizons containing carbonates were subsurface horizons. These had varying values of percent total carbonates in the fine earth fraction from 2.86% to 31.2%. The average amount of carbonates for strictly the C horizons was 24.2%, which is very close to the conservative estimate/assumption of 25% total calcareous material that is used in one of the following sections titled “Estimate of mass of carbonates lost and resultant bulk density.”

Depth to Carbonates Trend

Table 40 and Figure 42 below contain the depths to encountering carbonate minerals at Hallett and Wildin. Five of the seven outwash soil cores at Hallett and four of the six at Wildin were deep enough to capture carbonates. As stated previously, no carbonates were captured in the Avon Lake soil cores.

Table 40. Recorded depths to carbonate minerals at the Hallett and Wildin locations. Carbonate minerals were not found at Avon Lake.

Hallett ID	Depth to effervescence (cm)	Wildin ID	Depth to effervescence (cm)
H2B-6	127	W1A-5	71
H4B-3	44	W2B-4	63
H5B-5	55	W3A-3	50
H6B-3	47	W5B-4	75
H8A-3	48		
Average	48.5	Average	64.8

If the larger depth of 127 cm is considered an outlier, the average depth to carbonates measured at the northernmost location Hallett is 49 cm. The average depth to carbonates at Wildin to the southeast is 65 cm. At Avon Lake which is the most southeastern location, even though carbonates were not detected, the average depth of probing was 155 cm. That means the average depth to carbonate minerals is likely lower than 155 cm at that location. The trends shown by Table 40 and Figure 42 and the inability to detect carbonates at Avon Lake follow the trend of increasing MAP and MAT and show, within the soil, evidence of the climate gradient.

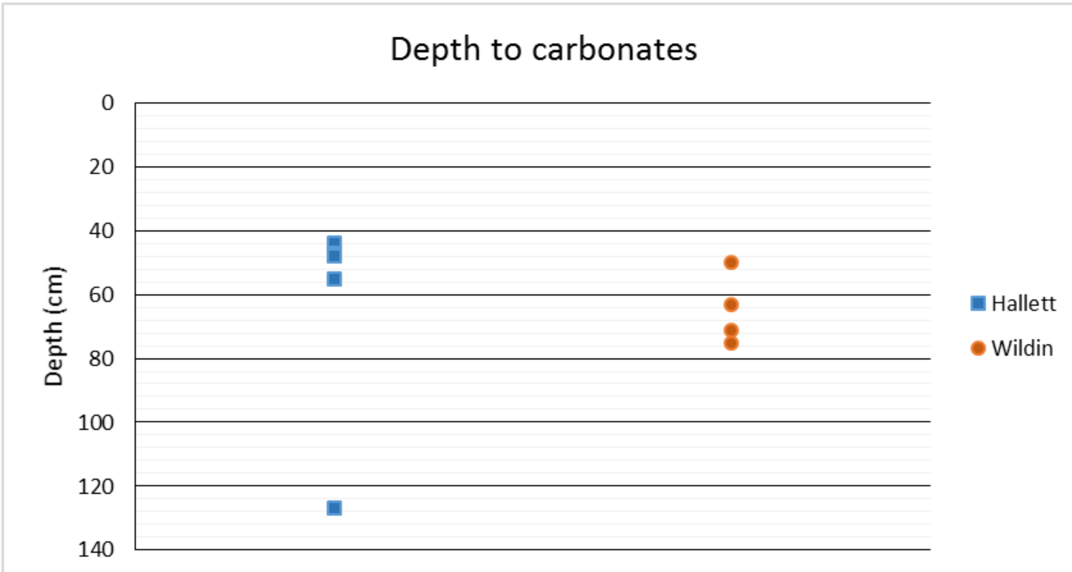

Figure 42. Recorded depths to carbonate minerals at the three locations.

Soil survey data

Five outwash derived soil series are commonly mapped on outwash terraces and outwash plains (sandar) of the DML and the research locations in this study. These are the Cylinder, Estherville, Linder, Salida, and Wadena series. Utilizing county soil surveys, data was retrieved and compiled for these series in every county of the DML. The specific data of interest was the depth to carbonates/effervescence. Data obtained from soil cores collected in this study were also incorporated. Average depth to carbonates was then calculated for each DML county in Iowa based on this data; however, the Salida series had to be excluded since it is partially defined by its abundance of calcareous sediments at or near the soil surface.

Average depth to carbonates (using the Cylinder, Estherville, Linder, and Wadena series) for each DML county in Iowa was plotted on a map of Iowa (Figure 43). Data points were placed in the center of each county polygon. Isobars were then fitted manually to help display any trend in the data. This same process was also done for just the counties surrounding the DMR (Figure 44).

A different approach was also applied to help observe the trend in the depth to carbonates across the DML in Iowa. Depth to carbonate data for each soil series: Cylinder, Estherville, Linder, and Wadena, were plotted on their own maps. Given that Wadena and Cylinder out of all the series are the most extensively mapped (from the Iowa-Minnesota border to the southern extent of the DML), they were the most useful to demonstrate any trend (Figures 45 and 46). Isobars of best fit were manually plotted as before.

The depth to carbonate trends for the Wadena and Cylinder series (Figures 45 and 46) show (and to a lesser extent the amalgamated outwash derived soils in Figures 43 and 44 as well) that carbonate minerals are leached out of the soil to an increasing depth along a northwest to southeast track across the DML. For example the depth to carbonates/effervescence in Cylinder soils in the northwest is much shallower than in the soils of the southeast (Figure 46).

Now using just the Cylinder series data in Figure 46 and the isobar intervals, a formula can be obtained. The map distance between the northwest corner of Emmet County and the northwest corner of Polk County is about 200 km. Across this 200 km distance, the depth to carbonates in the Cylinder series increases from approximately 60 cm to approximately 100 cm. Along this north-northwest to south-southeast track, the expected depth to carbonate minerals will increase approximately 10 cm about every 50 km.

The other three plots (Figures 43-45) show similar trends even if not as clear as that in the Cylinder series plotted data. This trend of course matches up well with the southeasterly trends of increasing MAP and MAT previously mentioned in the introduction.

Estimate of Mass of Carbonates Lost and Resultant Bulk Density

Two areas of interest in this study were to determine the volume of calcareous sediments that have been dissolved and lost from the upper part of the soil due to chemical reactions and leaching and to determine the value of the resulting bulk density following carbonate loss. If four pieces of information: depth to carbonates, bulk density of outwash, percent carbonates of outwash sediments, and fraction of retention of freed calcium and magnesium are known, then a rough estimate of mass of carbonates lost per area may be obtained.

Several assumptions were necessary to make to calculate estimates of carbonate loss. First, the outwash deposited at all locations has a uniform bulk density to a depth of 2 meters and has a uniform proportion of carbonate minerals. Based on data of Savage et al. (2000), the outwash bulk density at the time of deposition is assumed to be 1.6 g/cm^3. A conservative estimate of 25% total carbonates by mass constituted of 7% calcite and 18% dolomite is assumed based on data obtained from this study and U.S. Geological Survey (1958) data for Tazewell drift outwash.

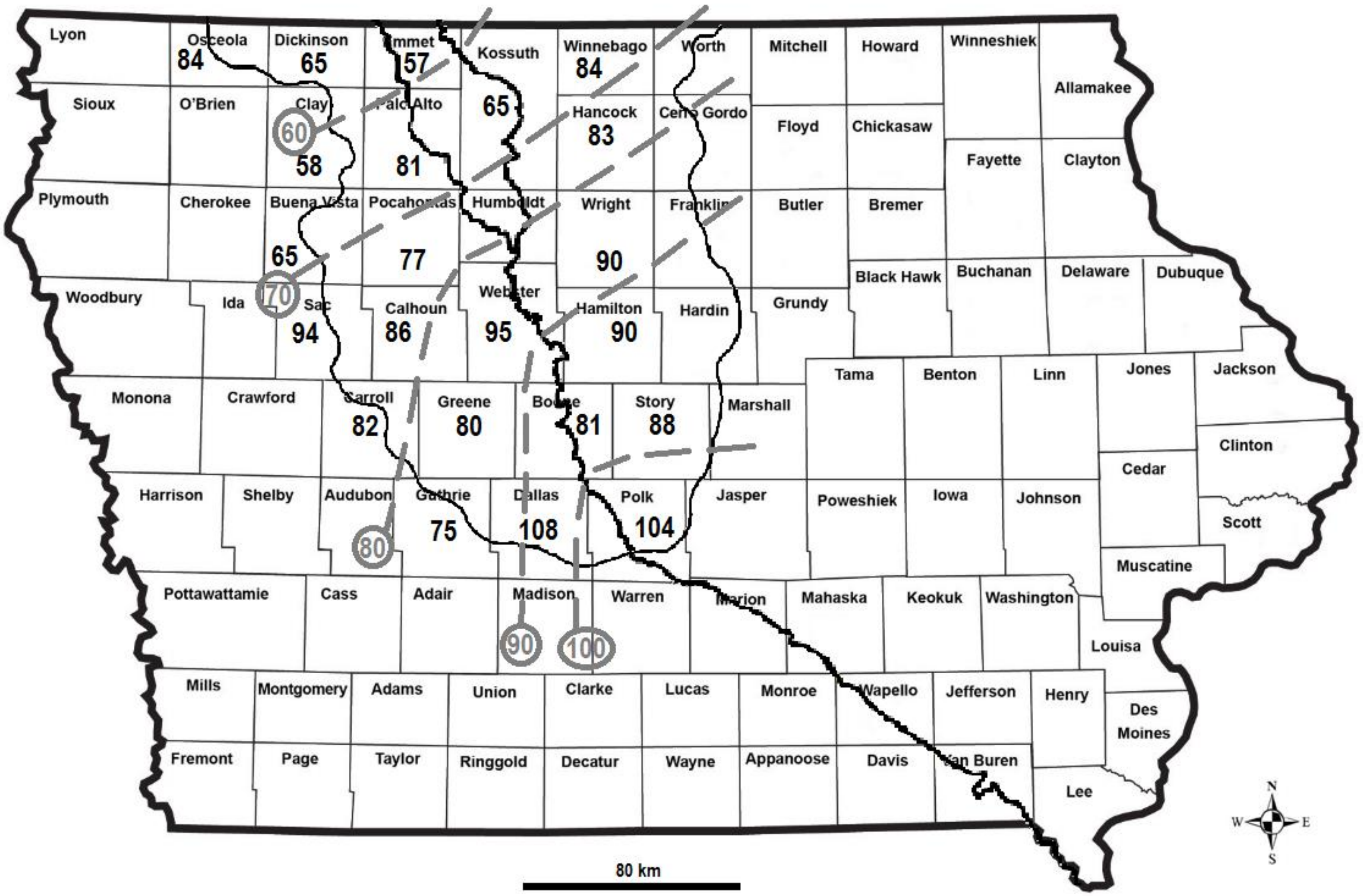

Figure 43. Mean depths (in cm) to carbonates/effervescence from the amalgamated series (Cylinder, Linder, Estherville, and Wadena) across the Des Moines Lobe in Iowa.

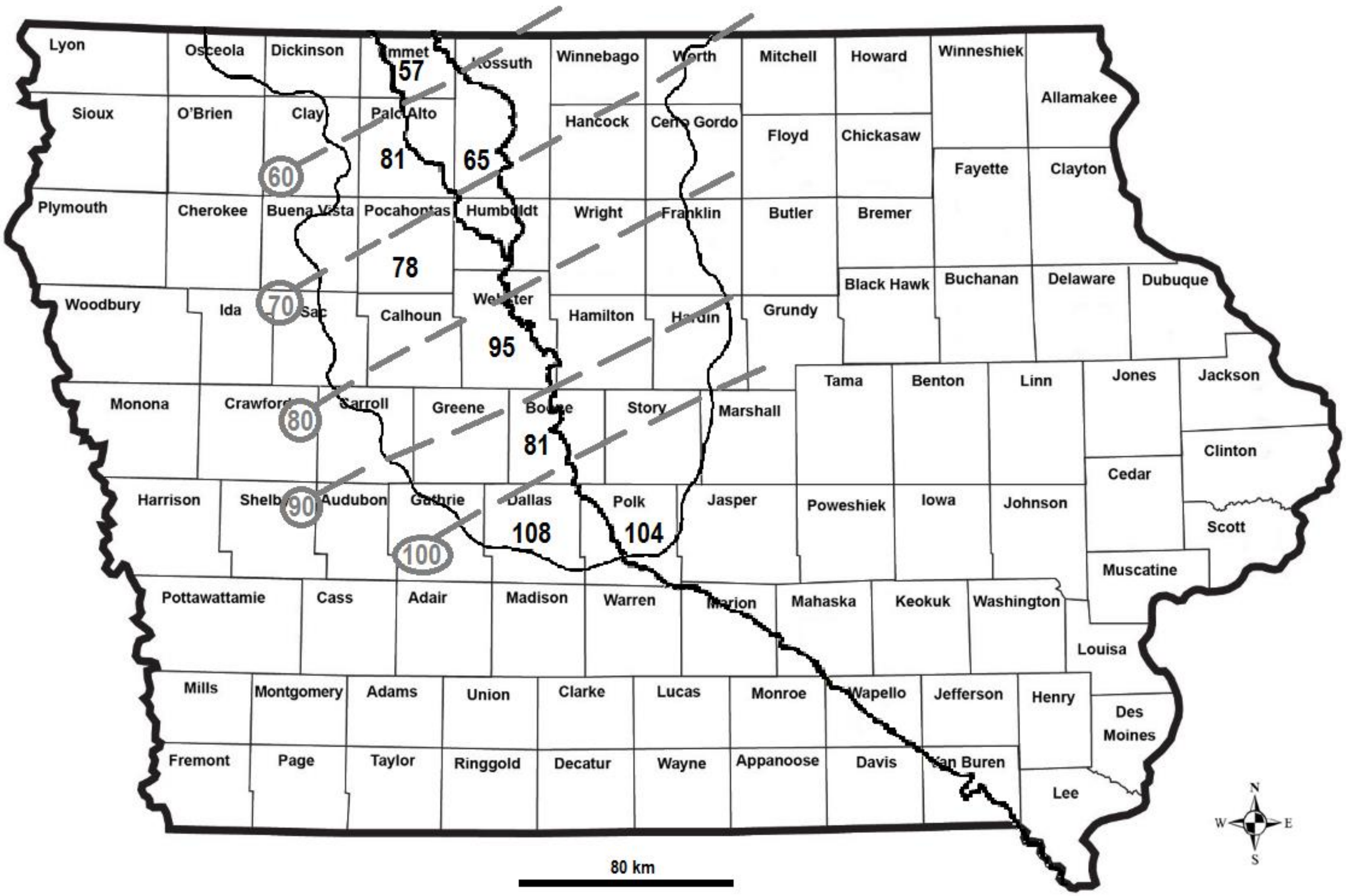

Figure 44. Mean depths (in cm) to carbonates/effervescence from the amalgamated series (Cylinder, Linder, Estherville, and Wadena) across only the Iowa Des Moines Lobe counties surrounding the Des Moines River.

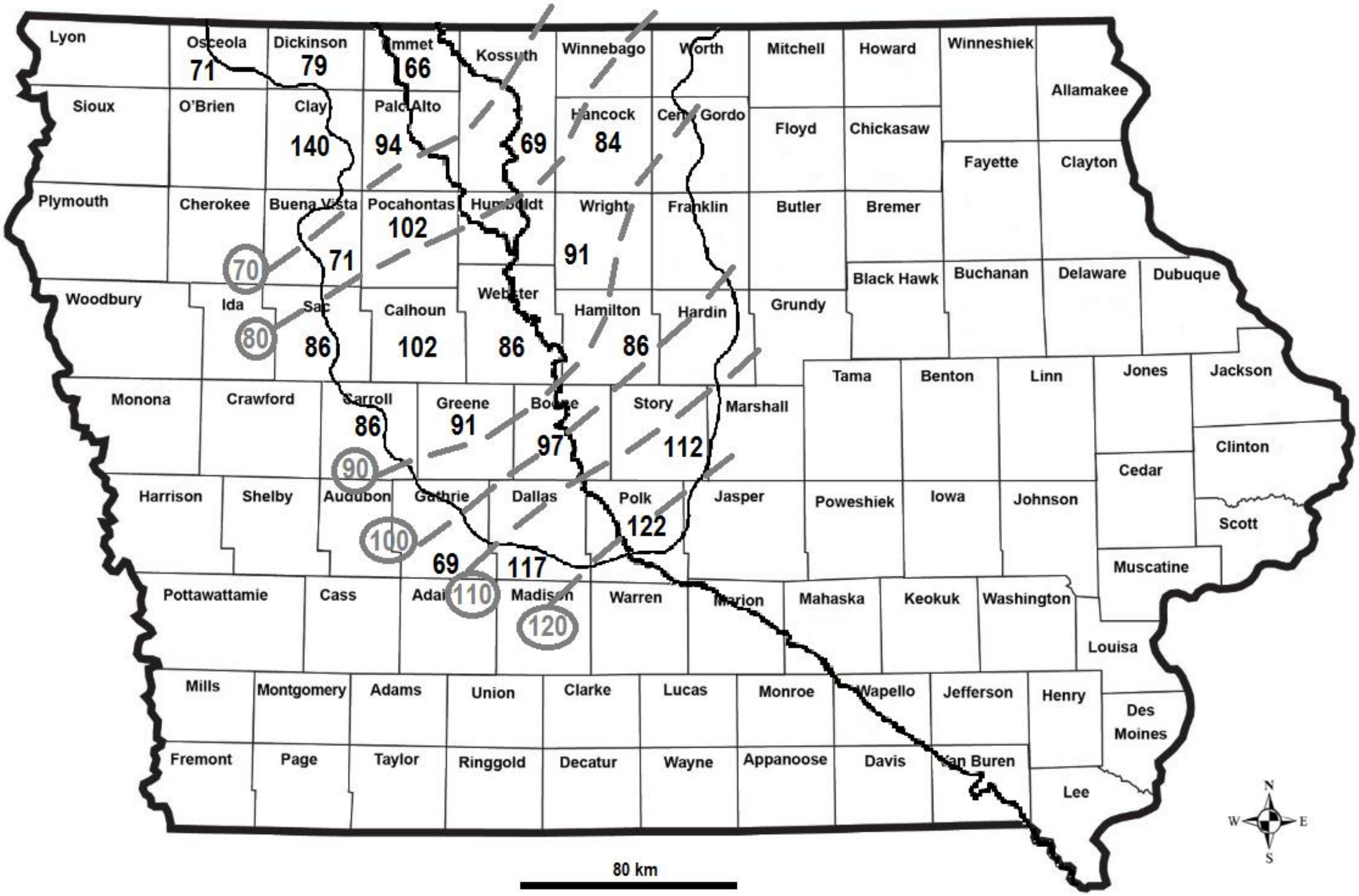

Figure 45. Depths (in cm) to carbonates/effervescence for the Wadena series across the Des Moines Lobe in Iowa.

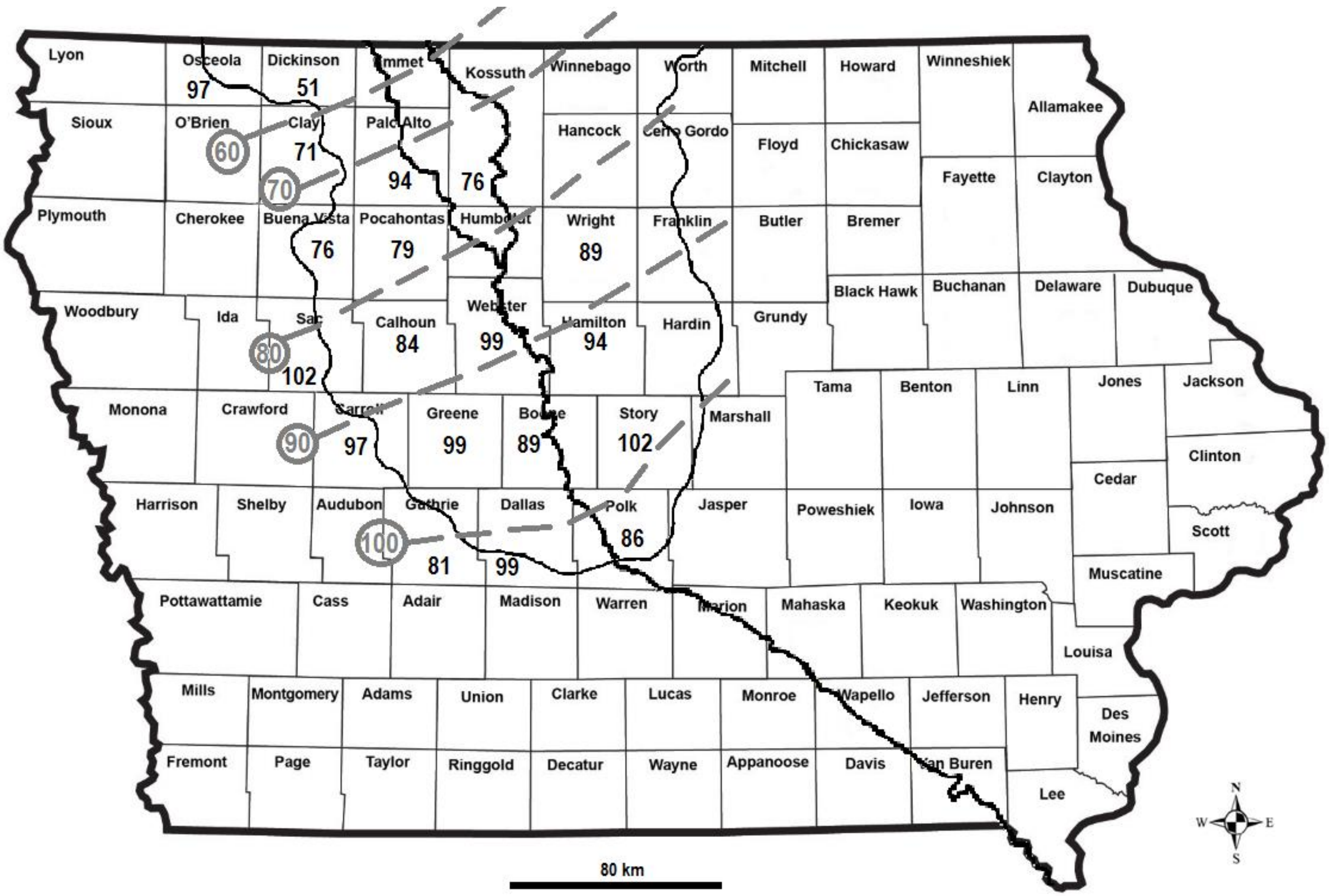

Figure 46. Depths (in cm) to carbonates/effervescence for the Cylinder Series across the Des Moines Lobe in Iowa.

An additional assumption was that the residual Ca and Mg still remaining within the upper solum after reaction and dissolution of these carbonate minerals with acidic compounds will be 50%. This value is based on West and McBride (2005) in which they propose a "conservative" value of 50% of Ca from applied agricultural lime amendments remaining in the upper soil three to four years after application. The remaining Ca and Mg is mostly held on clay minerals and SOM by cation exchange sites. The literature is lacking in a long term study of Ca and Mg retention in the soil from the dissolution of carbonates; West and McBride (2005) acknowledge this in their paper and settled on 50% as the best value to use for their purposes.

Using the assumptions just listed and an average of the depths to encountering carbonates recorded from the profile descriptions, estimates of the mass per area of carbonates lost can be made for each location as well as a prediction of the resultant bulk density excluding other pedological factors such as an increase in SOM and void/pore collapse. The estimates calculated for carbonates removed to the average depths at the three locations are listed in Table 41 below. The predicted bulk density for the zone devoid of carbonate minerals would be 1.27 g/cm^3. The example calculations for estimating resultant bulk density and amount of carbonates removed are presented below in Equations 16 through 21.

Table 41. Estimates of the mass of total carbonates removed from the surface of the sola to the depths listed.

Location	Average depth to carbonate minerals (cm)	Mass of total carbonates per area removed to specified depth (Mg/ha)
Hallett	48.5	1600
Wildin	64.8	2100
Avon Lake	>155.2	>5100

$CaCO_3$: Fraction of Ca retained in solum assumed to be 50% from leaching of $CaCO_3$

$$\frac{100.09g}{mol\ CaCO_3} - \left(\frac{40.08g}{mol\ CaCO_3} * 0.5\right) = \frac{80.05g\ lost}{mol\ CaCO_3}$$

Equation 16.

$$\frac{80.05g\ lost\ /\ mol\ CaCO_3}{100.09g/mol\ CaCO_3} = 0.800\ lost$$

Equation 17.

$CaMg(CO_3)_2$: Fraction of Ca and Mg retained in solum assumedt to 50% from leaching of $CaMg(CO_3)_2$

$$\frac{184.41g}{mol\ CaMg(CO_3)_2} - \left[\left(\frac{40.08g\ Ca}{mol\ CaMg(CO_3)_2} + \frac{24.31g\ Mg}{mol\ CaMg(CO_3)_2}\right) * 0.5\right] = \frac{152.22g\ lost}{mol\ CaMg(CO_3)_2}$$

Equation 18.

$$\frac{152.22g\ lost\ /\ mol\ CaMg(CO_3)_2}{184.41g/mol\ CaMg(CO_3)_2} = 0.825\ lost$$

Equation 19.

Example calculation: Mass of carbonates removed per area to 48.5 cm depth at Hallett

$$\left(\frac{0.07g\ CaCO_3}{1g\ outwash} * 0.800 + \frac{0.18g\ CaMg(CO_3)_2}{1g\ outwash} * 0.825\right) * \frac{1.6g\ outwash}{cm^3} * \frac{10^8 cm^2}{1ha} * 48.5cm * \frac{1Mg}{10^6 g} = \frac{1587Mg\ carbonates\ removed}{ha}$$

Equation 20.

Example calculation: Resultant bulk density following removal of carbonates from outwash

$$\left[1-\left(\frac{0.07g\ CaCO_3}{1g\ outwash}*0.800+\frac{0.18g\ CaMg(CO_3)_2}{1g\ outwash}*0.825\right)\right]*\frac{1.6g\ outwash}{cm^3}=\frac{1.27g\ soil}{cm^3}$$

Equation 21.

Soil Thin Section Analyses for Mineralogy

Using the program cellSens Dimension by Olympus, quick estimates of mineral groupings were made for mineral thin sections prepared from soil sampled from the midpoint of master horizons (e.g. Figure 47). These mineral groupings were “colorless minerals”, “pore space”, “clay/silt/OM/other”, and “brown concretions”. “Colorless minerals” included truly colorless to light tan minerals. “Pore space” showed up blue in the thin sections due to the blue dyed resin. “Brown concretions” showed up as very, very dark brown to black in color. The “clay/silt/OM/other” grouping was virtually all remaining colors. “Brown concretions” were present in almost every thin section. They are very distinct; however, they were a very minor constituent. The other three groups always made up the vast majority of the area.

In the image analysis program, colors were assigned to each grouping (Figure 47). The “colorless minerals” received the color yellow, “pore space” received the color red, “clay/silt/OM/other” received the color green, and “brown concretions” received the color purple. The program then summed all the color pixels assigned to a grouping in the image. Results were reported for area in units of square micrometers (μm^2) and for percent of total area (%).

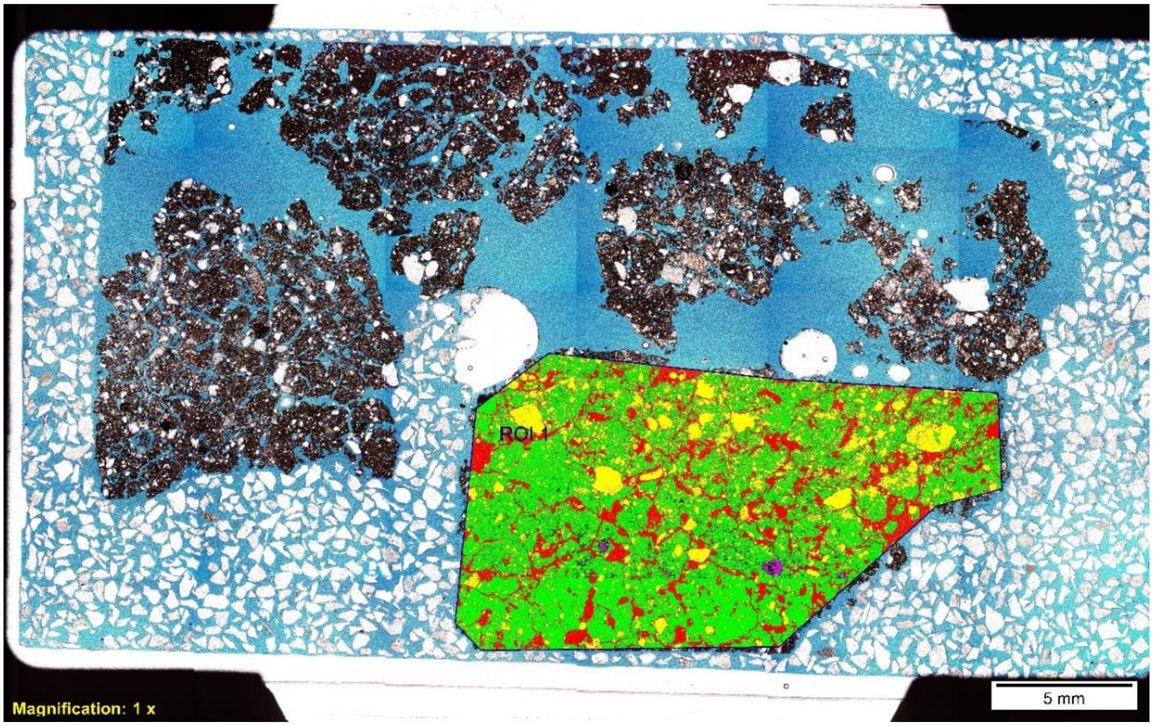

Figure 47. Region of interest selected over area of thin section W4B-2. The different colors represent different groupings.

Figure 48 is a graph of the percent cross-sectional area occupied by the colorless to light tan minerals versus depth of thin section sampling. This colorless mineral grouping is largely comprised of quartz and feldspar, but may include the carbonates when present. Even though there are slightly different y-intercepts for the linear trend lines, there is a trend that as one moves south and east from the Hallett location to the Avon Lake location that colorless minerals occupy less of the soil volume at lower depths. This is evidence of deeper soil development where the colorless minerals are lower in volume and more clay and/or SOM is present. The R^2 values increase across the state from Hallett to Avon Lake perhaps suggesting more variability in the northwest where MAT and MAP are lower. The soil forming factors: parent material, time, relief, and biota were held constant with MAP and MAT changing along the climate gradient.

Figure 48 contains more supporting evidence for differing degrees of soil development along a climosequence.

Percent pore space was measured by using this quick counting method in the image analysis program (data not presented). These porosities were consistently lower than those estimated by using the measured bulk densities and an assumed particle density of 2.65 g/cm^3. In fact the porosities obtained using the quick counting method were consistently too low to be realistic for Iowa soils. However, these porosities are likely proportional to the actual values. The mean, minimum, and maximum porosity values were 27%, 12%, and 47% respectively. Average porosity values for similar soils in Iowa are around 50% (Coultas and McCracken 1952).

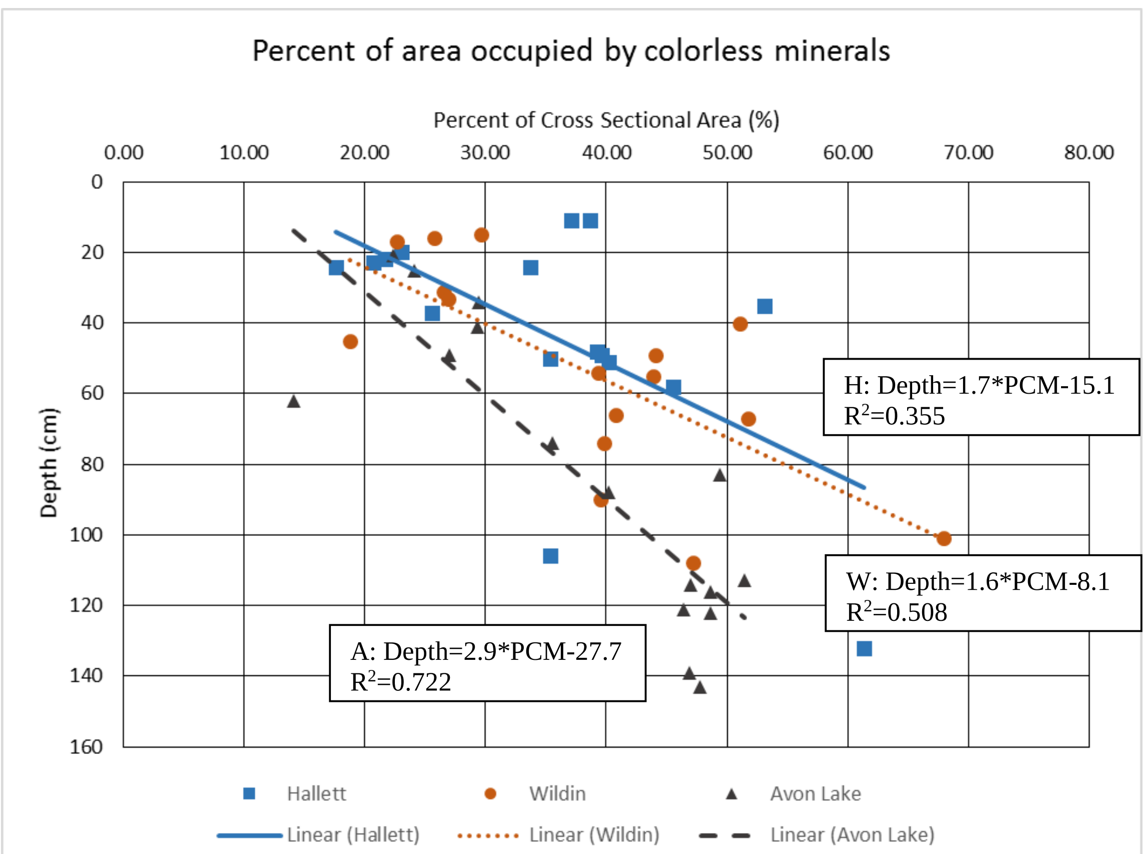

Figure 48. Percent of cross-sectional area of thin sections occupied by colorless to light tan minerals vs. depth. Linear trendlines and R^2 values are listed.

Point counting

To obtain excellent data on the mineralogy of the coarser soil particles (sand and pebbles), point counting would need to be performed. Due to time constraints, point counting of grains in every thin section slide was not possible in this study. Ideally 300 counts per slide would be performed using a grid with constant dimensions and following the method described in Ingersoll et al. (1984).

However, to gain a sense of what the mineral groupings may be constituted of, point counting was performed on three thin sections from the same profile, Wildin 3B. In the interest of time, only 100 counts were performed per slide following the procedure modified from Ingersoll et al. (1984). A 10 by 10 grid was placed over a mosaic image of each slide (Figure 49). The particle under each intersection was identified and assigned to one of the following categories: quartz, feldspar, pore space, clay/silt/OM, brown concretion, carbonates, or other lithic particles. The results of the point counting for thin sections W3B-1, W3B-2, and W3B-4 are shown in (Table 42).

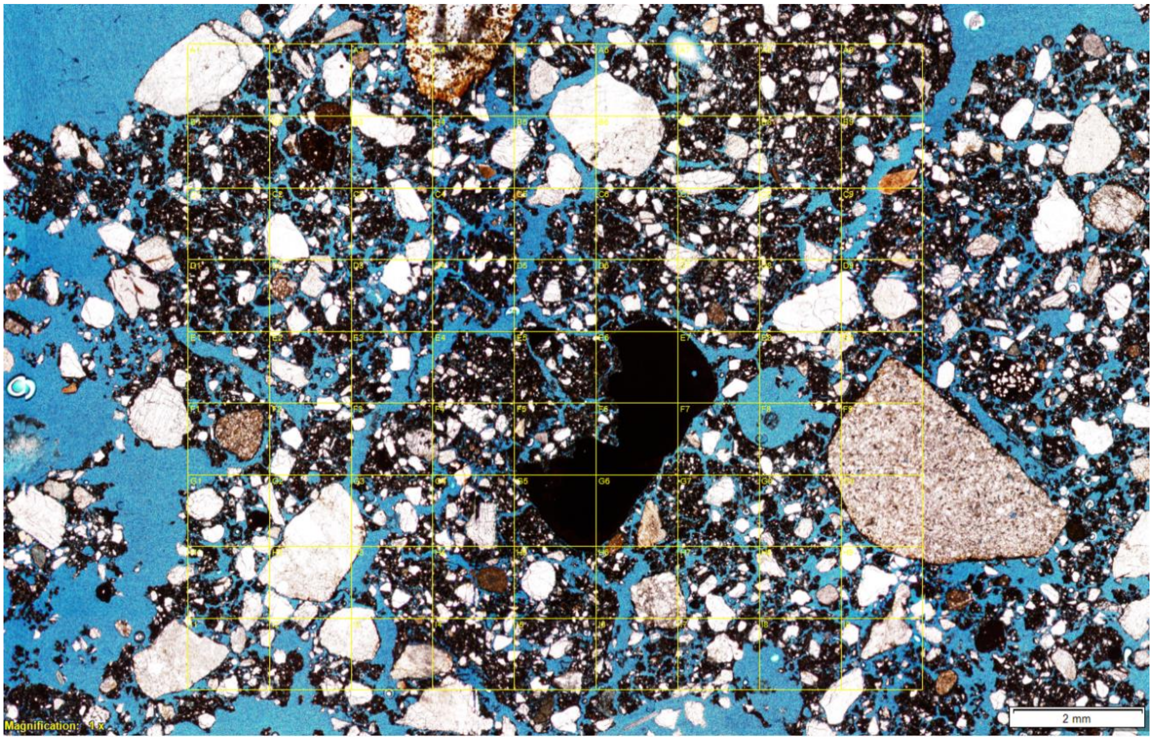

Figure 49. 10 by 10 grid overlaying slide W3B-1

Table 42. Point counting data for sand and pebble sized particles in thin sections W3B-1, W3B-2, and W3B-4.

Horizon ID	Quartz	Feldspar	Pore Space	Clay/ Silt/OM	Brown Concretion	Carbonates	Other Lithic Particles	Total
W3B-1	15	4	27	43	4	0	7	100
W3B-2	30	24	18	22	6	0	0	100
W3B-4	16	5	35	8	1	23	12	100

CHAPTER 4

CONCLUSIONS AND CLOSING REMARKS

Across the outwash derived soils of the three research locations, Hallett (northernmost near Estherville, IA), Wildin (middle location near Irvington, IA), and Avon Lake (southernmost near Carlisle, IA), trends in the soil properties and morphologies were observed that are credited primarily to pedological processes varying with the climate gradients of MAT and MAP. The SOC in the upper solum (upper two or three horizons) decreases with decreasing latitude while SOC in lower solum increases with decreasing latitude (Figure 37). Depth to carbonate minerals increases approximately 10 cm every 50 km from north-northwest to south-southeast. Abundance of colorless to tan colored minerals at lower depths decreases with decreasing latitude (Figure 48).

Other important observations that were noted: Clay amounts and mean particle size are inversely related (Figures 19-22, 27-30). Virtually all outwash derived soils examined had finer textured surface horizons overlying coarser textured subsurface horizons. Fewer coarse fragments, but about 5% more clay in the B horizons was observed at the southernmost site (Table 5). Bulk density for virtually all the soils sampled increases with depth, but no trend across the three locations was observed (Figures 15-18). There is remarkable laterally spatial variability in the depth to carbonate minerals across small areas. An estimate of the mass per area of carbonates removed to the depth effervescence was calculated. No trend in pH could be determined; human related causes vastly overshadow any natural influences on soil pH. Soil survey mapping accuracy to the correct soil series was poor with only seven sola sampled of the 25 sites matching the dominant soil series in their respective consociation (Tables 1-25 in Appendix A).

Other important observations pointing to the inherent variability in properties of outwash derived soils due to the variability in deposition were noted. Clay values across the three locations were variable and had high t-test values (Tables 18-23). Geometric mean particle size values similarly varied (Tables 12-14), and t-test values (Tables 15-17) do not indicate any trends with latitude across the locations.

Data collected and analyzed in this project support the null hypothesis that the loamy soil textures observed in the surface horizons are largely due to geological not pedological processes. In actuality, there is certainly influence of pedological processes in generating finer surface textures overlying the coarser textures such as physical and chemical weathering breaking particles in smaller particles and the dissolution of the carbonate minerals which would increase the clay fraction through the release of impurities. However, these are asserted to be secondary causes even though there could have been carbonate leaching of potentially 25% or more of the starting outwash mass. Finer loamy surface textures are likely due mostly to waning flow events following high flow events during the Late Wisconsinan.

Future research should include a more thorough analysis of the mineral thin sections including proper point counts for each slide (from the soils derived from outwash and not alluvium). This will undoubtedly aid in better understanding of the proportion of feldspar versus quartz within the A, B, and C horizons and perhaps even observe a trend across the three locations. Future work should also include x-ray diffraction to a) gain better knowledge of minor mineral constituents and b) identify any concentrations of the mineral zircon in the A and B horizons versus the relatively undisturbed parent material of the C horizons; concentrations would be possible indicators of void/pore collapse increasing the bulk density after removal of carbonates.

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APPENDIX A

SOIL PROFILE DESCRIPTIONS

Table 1. Profile description for H1A.

PROFILE: Hallett 1A	VEGETATION: Row crops (corn)
PROFILE CLASSIFICATION: Fine loamy over sandy-skeletal, mixed, superactive, mesic Typic Hapludoll	SLOPE POSITION: 1%
PROFILE SOIL SERIES: Wadena	COUNTY: Emmet
MAPPED CLASSIFICATION: Fine loamy over sandy, mixed, superactive, mesic Typic Hapludolls	GPS LOCATION: 348,227 E, 4,815,222 N
MAPPED SOIL SERIES: 108 - Wadena	DATE SAMPLED: Nov. 2014 DATE DESCRIBED: Jan. 6, 2015
EPIPEDON: Umbric (52+ cm)	SAMPLED BY: E.M. Dahlhauser DESCRIBED BY: E.M. Dahlhauser
SUBSURFACE HORIZONS/FEATURES: Cambic	CORE LENGTH: 52cm CORE DIAMETER: 63mm

					Texture				Structure				Coatings		Roots		Pores				Redox Features / Other			
Horizon	Horizon	Lower Depth (cm)	Bdry	Color (moist)	Class	% Clay	% Sand	% CF	Grade	Shape	Size	Consist. (moist)	Type	Amt	Amt	Size	Amt	Size	Eff.	pH (H2O)	Type	Color	Amt	Size
1	Ap	36	C	10YR 2/1	CL	29.8	28.7	1.37	1	sbk	f	vfr	-	-	c	vf	c	vf	-	5.26	-	-	-	-
2	2A	46	C	10YR 2/2	L	23.8	44.8	13.83	2	sbk	f	fr	-	-	f	vf	m	vf	-	5.47	Redox masses	10YR 3/3	c	m
3	2Bw	52+	-	10YR 3/3	VG-SCL	22.6	54.2	53.12	1	sbk	vf	vfr	-	-	f	vf	c	vf	-	4.99	-	-	-	-

Notes:

*Assuming about 10cm of human transported sediment on top of profile

*Adjacent to soil berm

Table 2. Profile description for H2B.

PROFILE: Hallett 2B	VEGETATION: Row crops (corn)
PROFILE CLASSIFICATION: Loamy over sandy, mixed, superactive, mesic Pachic Argiudoll	SLOPE POSITION: 4% footslope or backslope
PROFILE SOIL SERIES: Dakota taxadjunct (17 cm past typic)	COUNTY: Emmet
MAPPED CLASSIFICATION: Fine loamy over sandy, mixed, superactive, mesic Typic Hapludolls	GPS LOCATION: 348,225 E, 4,815,288 N
MAPPED SOIL SERIES: 108 - Wadena	DATE SAMPLED: Nov. 2014 DATE DESCRIBED: Jan. 7, 2015
EPIPEDON: Mollic (66 cm)	SAMPLED BY: E.M. Dahlhauser DESCRIBED BY: E.M. Dahlhauser
SUBSURFACE HORIZONS/FEATURES: Argillic	CORE LENGTH: 137cm CORE DIAMETER: 63mm

					Texture				Structure				Coatings		Roots		Pores				Redox Features / Other			
Horizon	Horizon	Lower Depth (cm)	Bdry	Color (moist)	Class	% Clay	% Sand	% CF	Grade	Shape	Size	Consist. (moist)	Type	Amt	Amt	Size	Amt	Size	Eff.	pH (H2O)	Type	Color	Amt	Size
1	Ap	18	G	10YR 2/1	L	21.7	49.1	0.75	1	sbk	f	vfr	-	-	c	vf	c	vf	-	5.61	-	-	-	-
2	A	58	C	10YR 2/1	L	26.3	35.6	0.10	1	sbk	m-f	vfr	-	-	c	vf	c	vf	-	6.17	-	-	-	-
3	AB	75	C	10YR 3/2 & 10YR 4/3	L	19.4	51.2	1.77	2	sbk	m-f	fr	-	-	c	vf	c	vf	-	6.05	-	-	-	-
4	BA	90	G	10YR 4/3	SL	19.4	58.8	3.64	2	sbk	m-f	fr	-	-	c	vf	c	vf	-	6.16	-	-	-	-
5	Bt	127	C	10YR 4/3	SCL	26.1	46.9	1.85	2 2	pr sbk	m m	fr	Clay 10YR 4/3 Silans		c	vf	m	vf	-	6.08	-	-	-	-
6	2BC	137+	-	10YR 4/4	G-SL	18.3	67.3	24.50	2	sbk	m-f	fr	-	-	-	-	f	vf	yes	6.92	Redox masses	5YR 5/8	f	f

Notes:

*Assuming about 10cm of human transported sediment on top of profile

*Between soil berm of gravel pit and steep slope up to bluff

*Intertwined vertical streaks of the two colors in the 3rd horizon

*Silans (fine, white sand coatings) observed on vertical faces of peds in the 5th horizon

*Based on observations in companion core Hallett 2A: Carbonate frags in 6th horizon readily effervesces. However, only large pebbles/frags (5-10mm) are present. Sand fraction does not seem to have carbonates.

Table 3. Profile description for H3A.

PROFILE: Hallett 3A	VEGETATION: Row crops (corn)
PROFILE CLASSIFICATION: Fine-loamy over sandy, mixed, superactive, mesic Pachic Argiudoll	SLOPE POSITION: 3% footslope or backslope
PROFILE SOIL SERIES: Wiota taxadjunct (more clay)	COUNTY: Emmet
MAPPED CLASSIFICATION: Sandy, mixed, mesic Typic Hapludolls	GPS LOCATION: 348,288 E, 4,815,454 N
MAPPED SOIL SERIES: 72 - Estherville	DATE SAMPLED: Nov. 2014 DATE DESCRIBED: Jan. 9, 2015
EPIPEDON: Umbric (79 cm)	SAMPLED BY: E.M. Dahlhauser DESCRIBED BY: E.M. Dahlhauser
SUBSURFACE HORIZONS/FEATURES: Argillic	CORE LENGTH: 165cm CORE DIAMETER: 63mm

					Texture				Structure				Coatings		Roots		Pores				Redox Features / Other			
Horizon	Horizon	Lower Depth (cm)	Bdry	Color (moist)	Class	% Clay	% Sand	% CF	Grade	Shape	Size	Consist. (moist)	Type	Amt	Amt	Size	Amt	Size	Eff.	pH (H2O)	Type	Color	Amt	Size
1	Ap	23	G	10YR 2/1	CL	32.2	20.7	0.24	1	sbk	f	vfr	-	-	c	vf	c	vf	-	5.38	-	-	-	-
2	A	70	G	10YR 2/1	SiCL	34.6	14.3	0.13	2	sbk	f	fr	-	-	c	vf	m	vf	-	5.44	-	-	-	-
3	AB	89	G	10YR 2/2 & 10YR 4/3	SiCL	35.7	14.2	0.87	2	sbk	f	fr	-	-	c	vf	m	vf	-	5.74	-	-	-	-
4	Bt1	101	C	10YR 4/3	SiC	42.8	7.6	0.26	2 2	sbk abk	f f	fr	Clay 10YR 4/3 Org. 10YR 2/2	f f	c	vf	m	vf	-	5.74	silans	-	f	-
5	Bt2	156	A	10YR 5/4	SiC	46.5	4.5	0.03	3 3	pr abk	m f	fi	Clay 10YR 4/3 Org. 10YR 2/2	c f	f	vf	m	vf	-	6.04	silans	-	c	-
6	2C	165+	-	10YR 5/6	LS	12.0	82.4	9.23	0	sgr		loose	-	-	-	-	m	vf	-	5.83	-	-	-	-

Notes:

*Maybe lacustrine sediments over outwash

*Far from soil berm of the gravel quarry. Core was taken close to boundary of soil map units 485B and 72. May exhibit properties of both series.

*Intertwined vertical streaks of the two colors in the 3rd horizon

*Observed a large 5mm pore in 5th horizon of companion core Hallett 3B

*Silans (fine, white sand coatings) observed on vertical faces of peds in the 5th horizon. May also be present in the 4th horizon.

Table 4. Profile description for H4B.

PROFILE: Hallett 4B	VEGETATION: Row crops (corn)
PROFILE CLASSIFICATION: Fine-loamy over sandy-skeletal, mixed, superactive, mesic Typic Hapludoll	SLOPE POSITION: 1% toeslope
PROFILE SOIL SERIES: Wadena taxajunct (shallower to gravel, 2BC horizon instead of Bw)	COUNTY: Emmet
MAPPED CLASSIFICATION: Coarse-loamy, mixed, superactive, mesic Aquic Hapludolls	GPS LOCATION: 348,425 E, 4,814,280 N
MAPPED SOIL SERIES: 224 - Linder	DATE SAMPLED: Nov. 2014 DATE DESCRIBED: Jan. 14, 2015
EPIPEDON: Mollic (44 cm)	SAMPLED BY: E.M. Dahlhauser DESCRIBED BY: E.M. Dahlhauser
SUBSURFACE HORIZONS/FEATURES:	CORE LENGTH: 56cm CORE DIAMETER: 63mm

					Texture				Structure				Coatings		Roots		Pores				Redox Features / Other			
Horizon	Horizon	Lower Depth (cm)	Bdry	Color (moist)	Class	% Clay	% Sand	% CF	Grade	Shape	Size	Consist. (moist)	Type	Amt	Amt	Size	Amt	Size	Eff.	pH (H2O)	Type	Color	Amt	Size
1	Ap	17	C	10YR 2/1	CL	27.3	38.6	2.55	1	sbk	vf	vfr	-	-	m	f	m	vf	-	5.67	-	-	-	-
2	A	44	C	10YR 2/1 10% 10YR 4/6	SCL	23.3	49.2	4.17	2	sbk	m	vfr	-	-	f	vf	m	vf	-	6.72	-	-	-	-
3	2BC	56+	-	10YR 4/4 10YR 4/6	G-SL	11.7	75.5	39.66	1	sbk	vf	vfr	-	-	c	vf	m	vf	-	7.12	-	-	-	-

Notes:

*Dark yellowish-brown channels (2-5mm) in 2nd horizon. Mostly vertical orientation. They comprise about 10% of the volume in the lower half of the 2nd horizon. About 2% in the upper half.

Possible explanations: Old root channels/worm channels filled with materials brought up from the 3rd horizon, or may just be redox masses (Fe concentrations).

*3rd horizon did not hold together well during collection. It was hard to determine structure. Lots of pebbles.

Table 5. Profile description for H5B.

PROFILE: Hallett 5B	VEGETATION: Row crops (corn)
PROFILE CLASSIFICATION: Sandy, mixed, mesic Pachic Hapludoll	SLOPE POSITION: 2-3% footslope
PROFILE SOIL SERIES: Estherville taxajunct (6cm past typic, a little more clay in A horizons)	COUNTY: Emmet
MAPPED CLASSIFICATION: Sandy, mixed, mesic Typic Hapludolls	GPS LOCATION: 348,188 E, 4,813,884 N
MAPPED SOIL SERIES: 72 - Estherville	DATE SAMPLED: Nov. 2014 DATE DESCRIBED: Jan. 17, 2015
EPIPEDON: Mollic (55 cm)	SAMPLED BY: E.M. Dahlhauser DESCRIBED BY: E.M. Dahlhauser
SUBSURFACE HORIZONS/FEATURES: Cambic	CORE LENGTH: 61cm CORE DIAMETER: 63mm

					Texture				Structure				Coatings		Roots		Pores				Redox Features / Other			
Horizon	Horizon	Lower Depth (cm)	Bdry	Color (moist)	Class	% Clay	% Sand	% CF	Grade	Shape	Size	Consist. (moist)	Type	Amt	Amt	Size	Amt	Size	Eff.	pH (H2O)	Type	Color	Amt	Size
1	Ap	16	G	10YR 2/1	L	25.3	40.1	2.61	1	sbk	f	vfr	-	-	m	vf	m	vf	-	6.24	-	-	-	-
2	A1	27	G	10YR 2/1	L	23.2	46.2	4.68	2	sbk	m	fr	-	-	m	vf	m	vf	-	5.97	Root chan.	10YR 3/3	c	3mm
3	2A2	41	C	10YR 2/2	G-SL	18.1	61.6	22.49	2	sbk	m	fr	-	-	c	vf	m	vf	-	5.79	Root chan.	10YR 3/3	f	3mm
4	2Bw	55	C	10YR 3/3	VG-SL	10.5	79.7	43.53	1	sbk	f	vfr	-	-	c	vf	c	vf	-	6.18	-	-	-	-
5	2BC	61+	-	10YR 3/4	VG-SL	6.2	73.7	39.71	1	sbk	f	vfr	-	-	c	vf	-	-	yes	7.29	-	-	-	-

Notes:

*In 3rd horizon, fine gravel is more abundant in the lowest 5cm. Transitional zone.

*When probing, there was very little gravel on the surface, but we encountered gravel shallow.

*Bulk densities calculated for hoizons 3,4,&5 may be off. 3rd Horizon was moderately disturbed during collection. Horizons 4&5 are very sandy and gravelly so the fell apart during collection.

*3 small highly weathered, dissintegrating rock frags in 3rd horizon observed. One of the frags was a granite frag. Another was a 20mm sandstone frag. 1 less weathered, sub-angular granite frag observed in upper 4th horizon. Other frags in 4th horizon are sub-rounded.

Table 6. Profile description for H6B.

PROFILE: Hallett 6B	VEGETATION: Row crops (corn)
PROFILE CLASSIFICATION: Sandy-skeletal, mixed, mesic Typic Hapludoll	SLOPE POSITION: 2-5% shoulder
PROFILE SOIL SERIES: Estherville taxadjunct (shallow to gravel)	COUNTY: Emmet
MAPPED CLASSIFICATION: Sandy-skeletal, mixed, mesic Entic Hapludolls	GPS LOCATION: 348,263 E, 4,813,876 N
MAPPED SOIL SERIES: 73B - Salida	DATE SAMPLED: Nov. 2014 DATE DESCRIBED: Jan. 17, 2015
EPIPEDON: Mollic (49+ cm)	SAMPLED BY: E.M. Dahlhauser DESCRIBED BY: E.M. Dahlhauser
SUBSURFACE HORIZONS/FEATURES: Cambic	CORE LENGTH: 49cm CORE DIAMETER: 63mm

		Lower			Texture				Structure				Coatings		Roots		Pores				Redox Features / Other			
Horizon	Horizon	Depth (cm)	Bdry	Color (moist)	Class	% Clay	% Sand	% CF	Grade	Shape	Size	Consist. (moist)	Type	Amt	Amt	Size	Amt	Size	Eff.	pH (H2O)	Type	Color	Amt	Size
1	Ap	22	C	10YR 2/1	SL	14.9	67.7	4.40	1 2	sbk sbk	f m	fr	-	-	m	vf	m	vf	-	4.73	-	-	-	-
2	2Bw1	47	C	10YR 3/3	VG-SL	11.0	78.3	35.39	1	sbk	f	vfr	-	-	c	vf	m	vf	-	5.42	-	-	-	-
3	2Bw2	49+	-	10YR 3/3	G-LS	7.9	77.9	25.52	1	sbk	vf	vfr	-	-	f	vf	m	vf	yes	6.48	-	-	-	-

Notes:

*Granite ghost (pseudomorph) at 37cm depth breaking into sand grains.

*When probing, there was very little gravel on the surface, but we encountered gravel shallow, about 46cm depth.

*I thought that the 3rd horizon had too much organic matter and not enough effervescence to be a C horizon.

*Described this profile as having 2 parent materials really only due to sharp increase in coarse fragments.

Table 7. Profile description for H7B.

PROFILE: Hallett 7B	VEGETATION: Row crops (corn)
PROFILE CLASSIFICATION: Sandy-skeletal, mixed, mesic Typic Hapludoll	SLOPE POSITION: 0-1% summit
PROFILE SOIL SERIES: Estherville taxadjunct (shallow to gravel)	COUNTY: Emmet
MAPPED CLASSIFICATION: Sandy, mixed, mesic Typic Hapludolls	GPS LOCATION: 348,413 E, 4,814,118 N
MAPPED SOIL SERIES: 34 - Estherville	DATE SAMPLED: Nov. 2014 DATE DESCRIBED: Jan. 15, 2015
EPIPEDON: Mollic (40+ cm)	SAMPLED BY: E.M. Dahlhauser DESCRIBED BY: E.M. Dahlhauser
SUBSURFACE HORIZONS/FEATURES: Cambic	CORE LENGTH: 40cm CORE DIAMETER: 63mm

					Texture				Structure				Coatings		Roots		Pores				Redox Features / Other			
Horizon	Horizon	Lower Depth (cm)	Bdry	Color (moist)	Class	% Clay	% Sand	% CF	Grade	Shape	Size	Consist. (moist)	Type	Amt	Amt	Size	Amt	Size	Eff.	pH (H2O)	Type	Color	Amt	Size
1	Ap	22	C	10YR 2/1	SL	17.2	59.0	5.50	1	sbk	vf-f	vfr	-	-	m	vf	c	vf	-	4.93	-	-	-	-
2	2Bw	40+	-	7.5YR 2.5/2	VG-SL	15.9	64.0	40.06	1	sbk	f	vfr	-	-	m	vf	c	vf	-	5.47	-	-	-	-

Notes:

*The 2nd horizon was disturbed during collecting.

*Approximately 75 meters north of UTM coordinates, large cobbles and small boulders were cropping out of the soil and on the soil surface in great abundance.

*Described this profile as having 2 parent materials really only due to sharp increase in coarse fragments.

Table 8. Profile description for H8A.

PROFILE: Hallett 8A	VEGETATION: Row crops (corn)
PROFILE CLASSIFICATION: Fine-loam over sandy-skeletal, mixed, superactive, mesic Pachic Hapludoll	SLOPE POSITION: 2% footslope
PROFILE SOIL SERIES: Wadena taxadjunct (pachic and gravel in cambic horizon)	COUNTY: Emmet
MAPPED CLASSIFICATION: Sandy, mixed, mesic Typic Hapludolls	GPS LOCATION: 348,319 E, 4,815,418 N
MAPPED SOIL SERIES: 34 - Estherville	DATE SAMPLED: Nov. 2014 DATE DESCRIBED: Jan. 13, 2015
EPIPEDON: Mollic (48 cm)	SAMPLED BY: E.M. Dahlhauser DESCRIBED BY: E.M. Dahlhauser
SUBSURFACE HORIZONS/FEATURES: Cambic	CORE LENGTH: 78cm CORE DIAMETER: 63mm

					Texture				Structure				Coatings		Roots		Pores				Redox Features / Other			
Horizon	Horizon	Lower Depth (cm)	Bdry	Color (moist)	Class	% Clay	% Sand	% CF	Grade	Shape	Size	Consist. (moist)	Type	Amt	Amt	Size	Amt	Size	Eff.	pH (H2O)	Type	Color	Amt	Size
1	Ap	21	C	10YR 2/1	CL	36.5	28.7	0.89	1	sbk	f	vfr	-	-	m	vf	c	vf	-	4.87	-	-	-	-
2	A	48	C	10YR 2/1	CL	31.1	33.5	3.38	2	sbk	m	vfr	-	-	c	vf	m	vf	-	5.50	-	-	-	-
3	2Bw	70	C	10YR 3/3 little10YR 2/2	G-SCL	23.2	54.1	31.53	1	sbk	m	vfr	-	-	c	vf	m	vf	-	6.14	-	-	-	-
4	2BC	78+	-	10YR 3/4	EG-SL	12.1	68.2	65.56	0	massive		loose	-	-	f	vf	m	vf	yes	7.33	-	-	-	-

Notes:

*In the 1st horizon, medium roots in the upper 4cm

*In the 2nd horizon, gravel probably due to frost-heave or burrowing animals

*In the 3rd horizon, dark brown color with pocketss of very dark brown

*In the 4th horizon, fine to very coarse sand. Most is medium sand.

*Assuming about 10cm of human transported sediment on top of profile

*About 20 meters from soil berm of gravel quarry. Due to this close proximity, there is a slight chance of a recent deposit of soil sediments from quarrying preparation activities (ie. The scraping off of overburden topsoil before active quarrying). Core was taken close to boundary of soil map units 34 and 72.

Table 9. Profile description for W1A.

PROFILE: Wildin 1A	VEGETATION: CRP grasses and herbaceous plants
PROFILE CLASSIFICATION: Fine-Loamy over sandy-skeletal, mixed, superactive, mesic, Cumulic Hapludoll	SLOPE POSITION: 1% Footslope
PROFILE SOIL SERIES: Cylinder taxadjuct (10% more sand, shallow to gravel, better drainage)	COUNTY: Kossuth
MAPPED CLASSIFICATION: Fine loamy over sandy, mixed, superactive, mesic Aquic Hapludolls	GPS LOCATION: 401,385 E, 4,763,006 N
MAPPED SOIL SERIES: 203 - Cylinder	DATE SAMPLED: Sept. 2014 DATE DESCRIBED: Jan. 25, 2015
EPIPEDON: Mollic (62 cm)	SAMPLED BY: E.M. Dahlhauser DESCRIBED BY: E.M. Dahlhauser
SUBSURFACE HORIZONS/FEATURES: Cambic	CORE LENGTH: 99cm CORE DIAMETER: 63mm

					Texture				Structure				Coatings		Roots		Pores				Redox Features / Other			
Horizon	Horizon	Lower Depth (cm)	Bdry	Color (moist)	Class	% Clay	% Sand	% CF	Grade	Shape	Size	Consist. (moist)	Type	Amt	Amt	Size	Amt	Size	Eff.	pH (H2O)	Type	Color	Amt	Size
1	A1	16	G	10YR 2/1	SCL	22.0	50.7	5.00	2	gr	f	fr	-	-	m	f	m	f	-	6.51	-	-	-	-
2	A2	52	C	10YR 2/1	SCL	24.4	49.5	4.34	2 1	sbk gr	m vf	fr	-	-	m	f	m	f	-	6.36	-	-	-	-
3	2A3	62	C	10YR 2/2	G-SL	18.8	66.9	28.70	1	sbk	f	vfr	-	-	m	f	m	vf	-	6.76	-	-	-	-
4	2Bw	71	C	10YR 4/3	VG-SL	14.5	74.2	38.48	1	sbk	f	vfr	-	-	m	vf	m	vf	-	6.74	-	-	-	-
5	2BC	82	C	10YR 4/2	VG-SL	9.1	75.0	35.64	1	sbk	f	vfr	organic	c	m	vf	c	vf	yes	7.64	-	-	-	-
6	2C	99+	-	7.5YR 4/6 little10YR 4/2	VG-SL	9.6	73.1	39.02	0	sgr		loose	-	-	c	vf	-	-	yes	7.81	-	-	-	-

Notes:

*Did not take notes on landscape position. Did not measure probing depth.

*In 1st horizon, a large 15mm diameter granite frag shows signs of weathering but mostly solid. I suspect that it was brought in by a plow from somewhere else in the field. This is because the granite ghost (pseudomorph) at 68cm is so broken down and disaggregated.

*Worm casts in the 1st horizon.

*At 67cm depth (near bottom of 4th horizon), observed a granite ghost (pseudomorph) about 30mm in diameter. It is in the form of coarse pink and white sand grains (fairly angular). Pink feldspar (orthoclase), white quartz. Intermixed with many shin, golden-lustered flakes of mica (biotite).

*In 4th horizon, also encountered some 10mm wide pieces of shale.

*In 6th horizon, secondary $CaCO_3$ precipitated cement on large (medium to coarse) gravel frags.

Table 10. Profile description for W2B.

PROFILE: Wildin 2B	VEGETATION: CRP grasses and herbaceous plants
PROFILE CLASSIFICATION: Fine-loamy over sandy-skeletal, mixed, superactive, mesic, Cumulic Hapludoll	SLOPE POSITION:
PROFILE SOIL SERIES: Cylinder taxadjuct (a bit more sand, shallow to gravel, better drainage)	COUNTY: Kossuth
MAPPED CLASSIFICATION: Sandy, mixed, mesic Typic Hapludolls	GPS LOCATION: 401,508 E, 4,762,988 N
MAPPED SOIL SERIES: 34 - Estherville	DATE SAMPLED: Sept. 2014 DATE DESCRIBED: June 15, 2015
EPIPEDON: Mollic (63 cm)	SAMPLED BY: E.M. Dahlhauser DESCRIBED BY: E.M. Dahlhauser
SUBSURFACE HORIZONS/FEATURES:	CORE LENGTH: 70cm CORE DIAMETER: 63mm

					Texture				Structure				Coatings		Roots		Pores				Redox Features / Other			
Horizon	Horizon	Lower Depth (cm)	Bdry	Color (moist)	Class	% Clay	% Sand	% CF	Grade	Shape	Size	Consist. (moist)	Type	Amt	Amt	Size	Amt	Size	Eff.	pH (H2O)	Type	Color	Amt	Size
1	A1	13	C	10YR 2/1	L	21.8	46.9	8.48	2	gr	m	fr	-	-	m	f-m	m	f-m	-	5.48	-	-	-	-
2	A2	34	C	10YR 2/1	L	24.9	43.9	5.20	1 1	sbk gr	m f	fr	-	-	c	vf-f	m	vf-f	-	5.44	-	-	-	-
3	2AB	63	C	10YR 2/2	VG-SL	19.2	64.6	42.60	1	sbk	m	fr	-	-	c	vf	m	vf-f	-	6.01	-	-	-	-
4	2BC	70+	-	10YR 4/3	VG-SL	10.6	72.0	49.67	0	sgr		loose	-	-	c	vf-m	-	-	yes	7.57	Weak CaCO3 cement on frags Ghosts			

Notes:

*Did not take notes on landscape position. Did not measure probing depth.

*In 1st horizon, abundant roots and shoots

*In 4th horizon, some weak cement on coarse frags. Also active breakdown of some coarse frags to sand grains.

Table 11. Profile description for W3A.

PROFILE: Wildin 3A	VEGETATION: CRP grasses and herbaceous plants
PROFILE CLASSIFICATION: Sandy, mixed, mesic Cumulic Hapludoll	SLOPE POSITION: 1%
PROFILE SOIL SERIES: Estherville taxadjunct (cumulic, 15cm past typic)	COUNTY: Kossuth
MAPPED CLASSIFICATION: Fine loamy over sandy, mixed, superactive, mesic Typic Hapludolls	GPS LOCATION: 401,247 E, 4,762,904 N
MAPPED SOIL SERIES: 108 - Wadena	DATE SAMPLED: Sept. 2014 DATE DESCRIBED: July 6, 2015
EPIPEDON: Mollic (64 cm)	SAMPLED BY: E.M. Dahlhauser DESCRIBED BY: E.M. Dahlhauser
SUBSURFACE HORIZONS/FEATURES: Cambic	CORE LENGTH: 104cm CORE DIAMETER: 63mm

					Texture				Structure				Coatings		Roots		Pores				Redox Features / Other			
Horizon	Horizon	Lower Depth (cm)	Bdry	Color (moist)	Class	% Clay	% Sand	% CF	Grade	Shape	Size	Consist. (moist)	Type	Amt	Amt	Size	Amt	Size	Eff.	pH (H2O)	Type	Color	Amt	Size
1	A	30	C	10YR 2/1	SCL	20.9	55.0	10.01	2 2	sbk gr	m f	fr	-	-	c	vf-f	m	vf-f	-	6.18	-	-	-	-
2	2Bw	50	C	10YR 3/2 to 10YR 3/3	VG-SL	12.4	78.6	44.92	1	sbk	f	fr	-	-	c	vf-f	c	vf-f	-	6.36	-	-	-	-
3	2BC	64	C	10YR 3/2	G-LS	8.2	81.6	31.03	1	sbk	f	vfr	-	-	c	vf	c	vf	yes	7.61	-	-	-	-
4	2C1	76	C	7.5YR 5/6	VG-LS	5.8	87.1	36.50	0	sgr		loose	-	-	f	vf	-	-	yes	7.89	-	-	-	-
5	2C2	104+	-	10YR 4/4	G-SL	10.5	78.6	32.82	0	sgr		loose	-	-	f	vf	-	-	yes	7.73	CaCO3 cement on frags		-	-

Notes:

*Did not take notes on landscape position. Did not measure probing depth.

*In 1st horizon, only 1 coarse lime frag (1.5cm) at 6cm depth.

*3rd horizon is odd. Primary carbonates present and some weak structure. Plenty of organic matter. I think the structure is purely due to roots and root exudates holding the soil particles together.

*4th horizon matrix color is strong orange-rust color.

*In 5th horizon, CaCO3 cement present on some large frags holding smaller frags to it. Some shale frags (5-10mm diameter) are weathering to soft clayey mush that occurs in a few isolated pockets around 90-95cm depth.

Table 12. Profile description for W4A.

PROFILE: Wildin 4A	VEGETATION: CRP grasses and herbaceous plants
PROFILE CLASSIFICATION: Fine-loamy over sandy-skeletal, mixed superactive, mesic, Cumulic Hapludoll	SLOPE POSITION: 2% Footslope
PROFILE SOIL SERIES: Spillville taxadjunct (alluvial fan deposit over outwash)	COUNTY: Kossuth
MAPPED CLASSIFICATION: Fine loamy over sandy, mixed, superactive, mesic Aquic Hapludolls	GPS LOCATION: 401,338 E, 4,762,856 N
MAPPED SOIL SERIES: 203 - Cylinder	DATE SAMPLED: Sept. 2014 DATE DESCRIBED: Jan. 21, 2015
EPIPEDON: Mollic (108 cm)	SAMPLED BY: E.M. Dahlhauser DESCRIBED BY: E.M. Dahlhauser
SUBSURFACE HORIZONS/FEATURES: Cambic	CORE LENGTH: 138cm CORE DIAMETER: 63mm

		Lower			Texture				Structure				Coatings		Roots		Pores				Redox Features / Other			
Horizon	Horizon	Depth (cm)	Bdry	Color (moist)	Class	% Clay	% Sand	% CF	Grade	Shape	Size	Consist. (moist)	Type	Amt	Amt	Size	Amt	Size	Eff.	pH (H2O)	Type	Color	Amt	Size
1	Ap	22	G	10YR 2/1	L	24.5	45.1	1.66	1	gr	f	fr	-	-	m	f	m	vf	-	5.47	Worm casts	-	-	-
2	A1	55	D	10YR 2/1	CL	30.0	35.8	1.24	1	sbk	f	fr	-	-	m	f	m	vf	-	5.92	-	-	-	-
3	A2	91	C	10YR 2/1	CL	32.3	29.9	1.61	2	sbk	m	fr	-	-	m	vf	m	vf	-	6.38	-	-	-	-
4	2AC1	108	C	10YR 3/2	VG-SCL	23.2	63.6	37.63	1	sbk	f	fr	-	-	c	vf	m	vf	-	6.52	Fe 5YR 4/6	& 5YR 3/4	c	4mm
																					Mn	10YR 2/1	f	3mm
5	2AC2	138+	-	10YR 4/2	G-SL	15.6	78.7	25.68	1	sbk	f	fr	-	-	f	vf	m	vf	-	6.74	Fe 10YR 4/6	& 5YR 3/4	c	4mm
																					Mn	10YR 2/1	c	5mm

Notes:

*Did not take notes on landscape position. Did not measure probing depth.

*In 1st horizon, worm casts

*In 4th horizon, Fe concentrations common but fewer than in 5th horizon. Common shiny, golden-lustered flakes of mica (biotite) mostly in the lower half of the horizon. 1 disintegrating granite ghost (pseudomorph) in the very uppermost portion of the horizon.

*In 5th horizon, intact granite coarse frags present. Many shiny, golden-lustered flakes of mica (biotite) throughout the horizon.

*Suspected weak clay films in 5th horizon at first, but texture seems to be too sand to really tell.

Table 13. Profile description for W5B.

PROFILE: Wildin 5B	VEGETATION: CRP grasses and herbaceous plants
PROFILE CLASSIFICATION: Loamy over sandy-skeletal, mixed, superactive, mesic Pachic Argiudoll	SLOPE POSITION:
PROFILE SOIL SERIES: Warsaw taxadjunct (pachic, shallower to gravel)	COUNTY: Kossuth
MAPPED CLASSIFICATION: Sandy, mixed, mesic Typic Hapludolls	GPS LOCATION: 401,416 E, 4,762,749 N
MAPPED SOIL SERIES: 34 - Estherville	DATE SAMPLED: Sept. 2014 DATE DESCRIBED: June 16, 2015
EPIPEDON: Mollic (58 cm)	SAMPLED BY: E.M. Dahlhauser DESCRIBED BY: E.M. Dahlhauser
SUBSURFACE HORIZONS/FEATURES: Argillic	CORE LENGTH: 119cm CORE DIAMETER: 63mm

		Lower			Texture				Structure				Coatings		Roots		Pores				Redox Features / Other			
Horizon	Horizon	Depth (cm)	Bdry	Color (moist)	Class	% Clay	% Sand	% CF	Grade	Shape	Size	Consist. (moist)	Type	Amt	Amt	Size	Amt	Size	Eff.	pH (H2O)	Type	Color	Amt	Size
1	A1	32	G	10YR 2/1	L	21.8	47.7	0.84	2	sbk	m	fr	-	-	c	vf-f	m	f-m	-	5.22	-	-	-	-
									2	gr	f													
2	A2	58	C	10YR 3/3	SCL	23.1	50.6	10.66	2	sbk	m	fr	-	-	c	vf-f	m	f-m	-	5.73	-	-	-	-
3	2BA	75	A	10YR 4/3	VG-SCL	21.1	65.4	35.24	1	sbk	m	fr	-	-	m	vf-f	m	vf-f	-	6.17	ghosts	-	-	-
4	2Bt	83	A	2.5Y 4/3	G-CL	28.0	35.3	18.57	1	sbk	vf	fr	weak clay		f	vf	c	vf	-	6.92	few dark coatings in fine root channels			
5	2C	119+	-	10YR 4/4	G-LS	9.3	81.1	33.37	0	sgr		loose	-	-	f	vf	-	-	yes	8.02	CaCO3 cement on frags		-	-

Notes:

*Did not take notes on landscape position. Did not measure probing depth.

*In 2nd horizon, some black streaks 10YR 2/1 in the upper portion of horizon, so I called a gradual boundary.

*Ghost (pseudomorph) in the 3rd horizon. Active breakdown of coarse frags to coarse sand. Photo taken.

*In 4th horizon, few dark coatings in fine root channels

*In 5th horizon, CaCO3 cement on coarse frags.

Table 14. Profile description for W6C.

PROFILE: Wildin 6C	VEGETATION: CRP grasses and herbaceous plants
PROFILE CLASSIFICATION: Fine-Loamy over sandy-skeletal, mixed, superactive, mesic, Cumulic Hapludoll	SLOPE POSITION: 1% Footslope
PROFILE SOIL SERIES: Cylinder taxadjunct (shallower to gravel, better drainage)	COUNTY: Kossuth
MAPPED CLASSIFICATION: Fine loamy over sandy, mixed, superactive, mesic Typic Hapludolls	GPS LOCATION: 401,443 E, 4,762,598 N
MAPPED SOIL SERIES: 108 - Wadena	DATE SAMPLED: Sept. 2014 DATE DESCRIBED: Mar. 2, 2015
EPIPEDON: Mollic (66+ cm)	SAMPLED BY: E.M. Dahlhauser DESCRIBED BY: E.M. Dahlhauser
SUBSURFACE HORIZONS/FEATURES: Cambic	CORE LENGTH: 66cm CORE DIAMETER: 63mm

					Texture				Structure				Coatings		Roots		Pores				Redox Features / Other			
Horizon	Horizon	Lower Depth (cm)	Bdry	Color (moist)	Class	% Clay	% Sand	% CF	Grade	Shape	Size	Consist. (moist)	Type	Amt	Amt	Size	Amt	Size	Eff.	pH (H2O)	Type	Color	Amt	Size
1	A1	16	G	10YR 2/1	L	25.0	41.1	2.05	2	gr	m	fr	-	-	m	vf	m	vf	-	5.61	-	-	-	-
2	A2	43	C	10YR 2/1	SCL	24.3	49.1	1.94	2	sbk	f-m	fr	-	-	m	vf	m	vf	-	5.17	-	-	-	-
3	2Bw	66+	-	10YR 3/3	VG-SL	19.2	69.9	35.32	1	sbk	f	fr	-	-	m	vf	m	vf	-	5.22	ghosts	-	-	-

Notes:

*Did not take notes on landscape position. Did not measure probing depth.

*In 3rd horizon, granite fragments (almost a ghost/pseudomorph) breaking into very coarse sand grains. 2 large 10mm diameter granite frags. At the bottom of 3rd horizon is a cluster of black flattened oval fragments of shale. Largest pieces are 5mm diameter.

Table 15. Profile description for J1A.

PROFILE: Jenkins 1A	VEGETATION: Row crops (corn)
PROFILE CLASSIFICATION: Fine-loamy, mixed, superactive, mesic, Cumulic Argiudoll	SLOPE POSITION: 0% Summit
PROFILE SOIL SERIES: Wiota taxadjunct (more sand, usually not mapped on DM Lobe)	COUNTY: Boone
MAPPED CLASSIFICATION: Fine loamy over sandy, mixed, superactive, mesic Aquic Hapludolls	GPS LOCATION: 422,048 E, 4,654,639 N
MAPPED SOIL SERIES: 203 - Cylinder	DATE SAMPLED: May 2015 DATE DESCRIBED: June 2015
EPIPEDON: Mollic (82 cm)	SAMPLED BY: E.M. Dahlhauser DESCRIBED BY: E.M. Dahlhauser
SUBSURFACE HORIZONS/FEATURES: Argillic	CORE LENGTH: 147cm CORE DIAMETER: 63mm

					Texture				Structure				Coatings		Roots		Pores				Redox Features / Other			
Horizon	Horizon	Lower Depth (cm)	Bdry	Color (moist)	Class	% Clay	% Sand	% CF	Grade	Shape	Size	Consist. (moist)	Type	Amt	Amt	Size	Amt	Size	Eff.	pH (H2O)	Type	Color	Amt	Size
1	Ap	19	C	10YR 2/1	SiL	24.2	20.6	3.86	1	sbk	f	fr	-	-	f	vf	c	f	-	6.25	-	-	-	-
2	A1	38	C	10YR 2/1	SiL	26.4	18.7	1.60	2	sbk	f-m	fr	-	-	f	vf-f	c	f	-	5.95	-	-	-	-
3	A2	60	C	10YR 2/1	SiL	24.4	21.6	0.01	3	sbk	m	fi	-	-	m	vf-f	c	f-m	-	5.66	-	-	-	-
4	AB	82	C	10YR 3/1 3% 10YR 4/2	L	24.0	26.9	0.00	2 3	pr sbk	m m	fi	perhaps weak clay films		c	vf-f	c	f-m	-	5.37	-	-	-	-
5	Bt1	108	C	10YR 4/3	L	21.3	44.8	0.01	2 3	pr sbk	m m	fi	clay 10YR 4/2 silans 10YR 5/2	f	c	vf-f	m	f-m	-	5.28	black organic coatings in pores		f	
6	Bt2	133	G	10YR 5/4	SiCL	37.7	13.0	0.01	3 2	pr abk	c m	fi	clay 10YR 4/2	m	c	vf	m	f-m	-	5.36	black organic coatings in pores		c	
7	Bt3	147+	-	10YR 5/4	CL	30.5	22.4	0.01	3 2	pr abk	c m	fr	clay 10YR 4/2 & 10YR 3/1	m	f	vf	m	f-m	-	5.38	Fe blk. org. coat. In pores	5R 4/6	f m	vf

Notes:

*Some compaction occurred in collecting the core.

*Some gravel on surface of site (1/2 dollar size up to 4in diameter)

*In 5th horizon, multiple colors due to organic coatings in pores, clay films, and silans.

*In 6th horizon, multiple colors due to organic coatings in pores and clay films

*In 7th horizon, multiple colors due to organic coatings in large pores, Fe concentrations and clay films. Fe concentrations are in thin veiny pores.

Table 16. Profile description for J2B.

PROFILE: Jenkins 2B	VEGETATION: Row crops (corn)
PROFILE CLASSIFICATION: Sandy, mixed, superactive, mesic, Pachic Hapludoll	SLOPE POSITION: 1% Summit
PROFILE SOIL SERIES: Wadena taxadjunct (leached, no clear 2nd PM in core, vf-m sand)	COUNTY: Boone
MAPPED CLASSIFICATION: Fine loamy over sandy, mixed, superactive, mesic Typic Hapludolls	GPS LOCATION: 421,930 E, 4,654,758 N
MAPPED SOIL SERIES: 308 - Wadena	DATE SAMPLED: May 2015 DATE DESCRIBED: June 2015
EPIPEDON: Mollic (52 cm)	SAMPLED BY: E.M. Dahlhauser DESCRIBED BY: E.M. Dahlhauser
SUBSURFACE HORIZONS/FEATURES: Cambic	CORE LENGTH: 141cm CORE DIAMETER: 63mm

					Texture				Structure				Coatings		Roots		Pores				Redox Features / Other			
Horizon	Horizon	Lower Depth (cm)	Bdry	Color (moist)	Class	% Clay	% Sand	% CF	Grade	Shape	Size	Consist. (moist)	Type	Amt	Amt	Size	Amt	Size	Eff.	pH (H2O)	Type	Color	Amt	Size
1	Ap	16	C	10YR 2/2 10YR 3/2	SL	14.7	55.0	2.80	1	sbk	vf	fr	-	-	f	vf	f	vf	-	5.90	-	-	-	-
2	A	34	C	10YR 3/2	SL	15.3	52.6	2.00	2	sbk	f	fr	-	-	f	vf	c	vf-f	-	5.93	-	-	-	-
3	Bw1	52	C	10YR 3/2 10YR 3/3	L	24.1	42.5	0.00	2	sbk	m	fr	Org. 10YR 2/1	f	f	vf	m	f-m	-	6.21	-	-	-	-
4	Bw2	82	G	10YR 3/4	SCL	23.1	51.5	0.01	2	sbk	m	fr	Org. 10YR 2/1	f	f	vf	m	f-c	-	6.32	-	-	-	-
5	C1	100	G	10YR 4/4	SL	12.9	78.8	0.02	1	sbk	f	vfr	-	-	f	vf	c	f	-	6.33	-	-	-	-
6	C2	141+	-	10YR 4/4	LS	8.7	84.4	0.03	0	sgr		loose	-	-	f	vf	f	vf	-	5.78	-	-	-	-

Notes:

*Probed to 150cm. Compacted to 133cm in probe. Most of the compaction is likely in the 6th horizon.

*Pebbles and stones on surface of site from 1/2 dollar size up to 10in diameter.

*Good sorting of sand, so it does not look like outwash. Very few coarse frags in this profile. Only present in upper two horizons. So why are there so many stones on the surface?

Table 17. Profile description for J3B.

PROFILE: Jenkins 3B	VEGETATION: Row crops (corn)
PROFILE CLASSIFICATION: Fine-loamy over sandy, mixed, superactive, mesic Typic Argiudoll	SLOPE POSITION: 0-0.5% Summit
PROFILE SOIL SERIES: Moingona	COUNTY: Boone
MAPPED CLASSIFICATION: Fine loamy over sandy, mixed, superactive, mesic Typic Hapludolls	GPS LOCATION: 421,855 E, 4,654,593 N
MAPPED SOIL SERIES: 308B - Wadena	DATE SAMPLED: May 2015 DATE DESCRIBED: June 2015
EPIPEDON: Mollic (35 cm)	SAMPLED BY: E.M. Dahlhauser DESCRIBED BY: E.M. Dahlhauser
SUBSURFACE HORIZONS/FEATURES: Argillic	CORE LENGTH: 136cm CORE DIAMETER: 63mm

		Lower			Texture				Structure				Coatings		Roots		Pores				Redox Features / Other			
Horizon	Horizon	Depth (cm)	Bdry	Color (moist)	Class	% Clay	% Sand	% CF	Grade	Shape	Size	Consist. (moist)	Type	Amt	Amt	Size	Amt	Size	Eff.	pH (H2O)	Type	Color	Amt	Size
1	Ap	21	C	10YR 3/1	L	14.8	38.0	2.57	1	sbk	vf	fr	-	-	f	vf	f	vf	-	5.57	-	-	-	-
2	A	35	C	10YR 3/2	L	19.1	31.1	0.66	2	sbk	f	fr	-	-	c	vf	c	f	-	5.47	-	-	-	-
3	BA	47	C	10YR 4/3	L	23.6	26.4	0.00	2	sbk	f	fr	org.	f	c	vf	c	f-m	-	5.86	-	-	-	-
4	Bt	92	G	10YR 4/3	CL	27.9	27.6	0.01	3 3	sbk abk	f f	fr	org. v. weak clay	c f	c	vf	c	f-m	-	6.11	-	-	-	-
5	2C1	118	C	10YR 5/4	LS	10.0	82.5	0.01	0	sgr		loose	org.	f	f	vf	f	vf-f	-	6.14	-	-	-	-
6	2C2	136+	-	10YR 4/3	SL	11.6	77.6	0.00	0	sgr		loose	-	-	f	vf	f	vf-f	-	5.62	Mn	black	f	

Notes:

*Probed to 150cm. Compacted to 136cm in the soil probe before removal. Then expanded to 144cm.

*Few fist-sized stones on surface. Many pebbles though (smaller than 1in diameter). Sand in lower profile was clearly compacted by probing.

*In this core's duplicate Jenkins 3A, several white 3mm diameter hard bits were present to the plowing depth of about 21cm. These bits readily effervesced with the dilute hydrochloric acid.

I assume that these are crushed agricultural ammendment lime since there were no carbonates present elsewhere in the profile.

*In the 6th horizon, color difference may be due to an alluvial deposit of different composition.

Table 18. Profile description for J4A.

PROFILE: Jenkins 4A	VEGETATION: Row crops (corn)
PROFILE CLASSIFICATION: Fine-loamy over sandy, mixed, superactive, mesic, Mollic Hapludalf	SLOPE POSITION: 2% Backslope
PROFILE SOIL SERIES: Sattre taxadjunct (less sand in upper profile, stronger structure in Bt)	COUNTY: Boone
MAPPED CLASSIFICATION: Fine-loamy, mixed, superactive, mesic Cumulic Endoaquolls	GPS LOCATION: 421,741 E, 4,654,564 N
MAPPED SOIL SERIES: 135 - Coland	DATE SAMPLED: May 2015 DATE DESCRIBED: June 2015
EPIPEDON: Ochric	SAMPLED BY: E.M. Dahlhauser DESCRIBED BY: E.M. Dahlhauser
SUBSURFACE HORIZONS/FEATURES: Argillic	CORE LENGTH: 140cm CORE DIAMETER: 63mm

					Texture				Structure				Coatings		Roots		Pores				Redox Features / Other			
Horizon	Horizon	Lower Depth (cm)	Bdry	Color (moist)	Class	% Clay	% Sand	% CF	Grade	Shape	Size	Consist. (moist)	Type	Amt	Amt	Size	Amt	Size	Eff.	pH (H2O)	Type	Color	Amt	Size
1	Ap1	21	A	10YR 3/2	SiL	17.3	28.1	2.13	1	sbk	f	fr	-	-	f	vf	f	vf	-	6.33	-	-	-	-
2	Ap2	32	C	10YR 4/3	SiL	23.2	19.0	0.05	2	sbk	f	fr	org. 10YR 3/1	3%	f	vf	c	vf-f	-	6.33	Depletions Fe Conc.	10YR 5/3 5YR 4/6	f f	
3	BE	50	G	10YR 4/3 10YR 4/4	SiCL	27.6	12.4	0.00	2	sbk	m	fr	org. 10YR 3/1	1%	f	vf	c	vf-f	-	6.34	-	-	-	-
4	Bt1	98	G	10YR 5/4	SiCL	31.2	5.6	0.00	1 2	pr abk	m f-m	fr	clay 10YR 4/4 org. 10YR 3/1	f 1%	c	vf	m	vf-m	-	6.25	-	-	-	-
5	Bt2	116	C	10YR 5/4	SiC	40.9	4.2	0.02	1 3	pr abk	m f-m	fi	clay 10YR 4/4 org. 10YR 3/1	c 1%	f	vf	c	vf-f	-	4.99	Depletions Fe Conc.	10YR 5/2 5YR 4/6	f f	c f
6	2Bt3	134	C	10YR 4/4	SL	18.6	61.3	0.02	2 2	pr abk	m f-m	fr	perhaps clay blk. org. coat. In po		f	vf	c	vf-f	-	5.21	Depletions Fe Conc.	10YR 5/2 5YR 4/6	f f	c m
7	2C	140+	-	10YR 4/4 10YR 5/6	SL	12.5	76.1	0.10	0	sgr		loose	-	-	-	-	f	vf	-	5.55	-	-	-	-

Notes:

*1in diameter gravel pebbles and some fist-sized stones on surface.

*Probed to 144cm. Had 138cm in probe tube. So some compaction in the lower two horizons.

*In the 1st horizon, white hard bits of agricultural ammendment lime that readily effervesce (about 3mm diameter). Otherwise no carbonates present.

*In 2nd and 3rd horizon, organic coatings and infills of pores that look like perhaps old root channels or ant/worm tunnels.

Table 19. Profile description for J5A.

PROFILE: Jenkins 5A	VEGETATION: Row crops (corn)
PROFILE CLASSIFICATION: Loamy over sandy, mixed, superactive, mesic Typic Hapludoll	SLOPE POSITION: 0.5% Shoulder
PROFILE SOIL SERIES: Wadena taxadjunct (leached, no clear 2nd PM in core, vf-m sand)	COUNTY: Boone
MAPPED CLASSIFICATION: Fine loamy over sandy, mixed, superactive, mesic Typic Hapludolls	GPS LOCATION: 421,560 E, 4,654,579 N
MAPPED SOIL SERIES: 308B - Wadena	DATE SAMPLED: May 2015 — DATE DESCRIBED: June 2015
EPIPEDON: Mollic (28 cm)	SAMPLED BY: E.M. Dahlhauser — DESCRIBED BY: E.M. Dahlhauser
SUBSURFACE HORIZONS/FEATURES: Cambic	CORE LENGTH: 140cm — CORE DIAMETER: 63mm

					Texture				Structure				Coatings		Roots		Pores				Redox Features / Other			
Horizon	Horizon	Lower Depth (cm)	Bdry	Color (moist)	Class	% Clay	% Sand	% CF	Grade	Shape	Size	Consist. (moist)	Type	Amt	Amt	Size	Amt	Size	Eff.	pH (H2O)	Type	Color	Amt	Size
1	Ap1	10	C	10YR 3/1	L	18.2	44.9	2.24	1	sbk	vf	fr	-	-	f	vf	c	vf-f	-	6.20	-	-	-	-
2	Ap2	28	A	10YR 3/1 2% 10YR 4/3	L	16.9	48.1	2.59	2	sbk	f	fr	-	-	c	vf	c	f	-	6.29	-	-	-	-
3	Bw1	62	G	10YR 4/3	SL	13.5	62.5	0.01	2	sbk	m	vfr	-	-	f	vf	c	vf-f	-	6.49	-	-	-	-
4	Bw2	81	C	10YR 4/3	SL	18.8	52.8	0.00	2	sbk	m	fr	-	-	f	vf	m	vf-m	-	6.57	dark coatings in isolated layers	10YR 3/2	35%	
5	BC	119	C	10YR 4/3 to 10YR 4/4	SL	11.3	71.8	0.02	1	sbk	m	vfr	-	-	f	vf	c	f-m	-	6.70	dark coatings in isolated layers	10YR 3/2	10%	
6	C	140+	-	10YR 5/4 & band 10YR4/3	LS	8.3	81.5	0.00	0	sgr		loose	-	-	-	-	f	vf	-	6.53	-	-	-	-

Notes:

*Stones of 1/2 dollar up to 10in diameter present on the surface. Fine sand in lower half observed in field. Good sorting of sand, so it does not look like outwash.

*Probed to 147cm. Got 132cm in the probe tube, so clearly some compaction.

*In 5th horizon, 10% of horizon is isolated layers of dark coatings

*In 6th horizon, there is a band of darker color from 131-136cm depth.

*Interpret the darker horizontal layers in horizons 5 and 6 as being darker because of different depositions of sands. Interbedding of sands of different mineral and textural compositions perhaps.

Table 20. Profile description for J6B.

PROFILE: Jenkins 6B	VEGETATION: Row crops (corn)
PROFILE CLASSIFICATION: Sandy over fine-loamy, mixed, superactive, mesic Mollic Hapludalf	SLOPE POSITION: 3.5% Backslope
PROFILE SOIL SERIES: Sattre taxadjunct (inverted, decrease in sand with depth)	COUNTY: Boone
MAPPED CLASSIFICATION: Fine-loamy over sandy, mixed, superactive, mesic Mollic Hapludalfs	GPS LOCATION: 421,372 E, 4,654,684 N
MAPPED SOIL SERIES: 778B - Sattre	DATE SAMPLED: May 2015 DATE DESCRIBED: June 2015
EPIPEDON: Ochric	SAMPLED BY: E.M. Dahlhauser DESCRIBED BY: E.M. Dahlhauser
SUBSURFACE HORIZONS/FEATURES: Argillic	CORE LENGTH: 119cm CORE DIAMETER: 63mm

					Texture				Structure				Coatings		Roots		Pores				Redox Features / Other			
Horizon	Horizon	Lower Depth (cm)	Bdry	Color (moist)	Class	% Clay	% Sand	% CF	Grade	Shape	Size	Consist. (moist)	Type	Amt	Amt	Size	Amt	Size	Eff.	pH (H2O)	Type	Color	Amt	Size
1	Ap	19	A	10YR 3/2	SL	11.1	66.3	3.64	1	sbk	vf	fr	-	-	f	vf	f	vf-f	-	4.69	-	-	-	-
2	BA	62	G	10YR 3/2 to 10YR 4/2	CL	27.7	37.2	0.48	3	sbk	m	fr	-	-	m	vf-m	m	vf-f	-	5.91	-	-	-	-
3	Bt1	86	C	10YR 4/3	CL	28.9	29.4	0.16	3 to 3	sbk abk	m m	fr	perhaps clay 10YR 3/2		m	vf-f	m	vf-f	-	6.35	-	-	-	-
4	Bt2	102	C	10YR 4/3	CL	33.5	21.3	0.59	3 to 3	pr abk	m m	fi	clay 10YR 4/2	m	c	vf-f	c	vf-m	-	6.34	-	-	-	-
5	Bt3	119+	-	10YR 5/4	SiCL	36.3	16.3	0.10	3 to 3	pr abk	m m	fi	clay 10YR 4/3	m	c	vf-f	c	vf-m	-	6.42	-	-	-	-

Notes:

*1/2 dollar to 10in diameter sized stones on surface. Sand on surface. Sandy upper portion. Probe met with resistance and stopped around 115cm depth probably due to high increase in clay.

*Probed to 122cm. Had 119cm in probe tube. Little compaction.

*In 1st horizon, observed a large angular orangish fragment that was likely clay drainage tile.

*In 1st horizon of companion core Jenkins 6A, observed 2 more large frags 10mm and 40mm in size. Larger frag was rusty brown with small sparkles inside.

*In 4th and 5th horizons, coarse sand present.

*I struggled with horizonation in the middle of the core. I did not observe any platy structure, so I do not think there is an E horizon present in this core.

*1st horizon may be enriched in sand because it is a lag deposit on the backslope while silt is washed downslope.

Table 21. Profile description for A1A.

PROFILE: Avon Lake 1A	VEGETATION: Row crops (no-till soybeans)
PROFILE CLASSIFICATION: Fine-loamy over sandy, mixed, superactive, mesic Pachic Argiudoll	SLOPE POSITION: 0% Footslope
PROFILE SOIL SERIES: Wiota taxadjunct (more sand in A & B horizons, more clay in Bt)	COUNTY: Polk
MAPPED CLASSIFICATION: Fine loamy over sandy, mixed, superactive, mesic Typic Hapludolls	GPS LOCATION: 457,905 E, 4,596,911 N
MAPPED SOIL SERIES: 108 - Wadena	DATE SAMPLED: May 2015 DATE DESCRIBED: June 2015
EPIPEDON: Umbric (67 cm)	SAMPLED BY: E.M. Dahlhauser DESCRIBED BY: E.M. Dahlhauser
SUBSURFACE HORIZONS/FEATURES: Argillic	CORE LENGTH: 196cm CORE DIAMETER: 63mm

					Texture				Structure				Coatings		Roots		Pores				Redox Features / Other			
Horizon	Horizon	Lower Depth (cm)	Bdry	Color (moist)	Class	% Clay	% Sand	% CF	Grade	Shape	Size	Consist. (moist)	Type	Amt	Amt	Size	Amt	Size	Eff.	pH (H2O)	Type	Color	Amt	Size
1	Ap	13	A	10YR 3/1	L	21.6	33.7	0.03	1	sbk	vf	fr	-	-	c	vf-f	c	vf	-	5.08	-	-	-	-
2	A1	29	C	10YR 3/1	L	26.9	30.1	0.01	2	sbk	f	fr	-	-	c	vf-f	m	vf-f	-	4.78	-	-	-	-
3	A2	42	G	10YR 3/1	CL	33.3	20.1	0.00	1 2	sbk gr	f vf	fr	-	-	c	vf-f	m	vf	-	5.30	-	-	-	-
4	AB	67	G	10YR 3/1 to 10YR 3/2	CL	38.0	22.2	0.00	2	sbk	vf	fr	-	-	f	vf	m	vf	-	5.14	-	-	-	-
5	Bt	90	C	10YR 4/3	C	48.4	24.1	0.01	3	sbk	m	fr	organoargillands 10YR 3/2	c	f	vf	m	vf	-	4.92	-	-	-	-
6	2BC	114	C	10YR 4/4	SCL	27.8	64.9	0.83	1	sbk	m	fr	org. 10YR 3/2		f	vf	f	vf	-	5.13	-	-	-	-
7	2C	196+	-	10YR 4/4	LS	10.7	87.7	4.73	0	sgr		loose	-	-	-	-	-	-	-	5.27	ghosts	-	-	-

Notes:

*Probed to about 200cm depth.

*No stones on surface. However, outwash is clearly present below 90cm. No buried A horizon. Lee suggested in the field that this could perhaps be a welded profile (gradual deposition of sediment creating a continuous profile.

*Saved a 6cm long cylinder of soil from 7th horizon that could be used for creating a thin section

*In the 7th horizon, some large clasts (frags) present. Also observed an intensely weathered clast that is becoming a ghost (pseudomorph). -Photo taken.

*Upper solum is likely derived from sandy-silty alluvium overlying the outwash, but do not know where the switch occurs. Probably at the 6th horizon.

Table 22. Profile description for A2A.

PROFILE: Avon Lake 2A	VEGETATION: Row crops (no-till soybeans)
PROFILE CLASSIFICATION: Fine-loamy over sandy, mixed, superactive, mesic Cumulic Hapludoll	SLOPE POSITION: 1% Footslope
PROFILE SOIL SERIES: Fort Dodge	COUNTY: Polk
MAPPED CLASSIFICATION: Fine-loamy, mixed, superactive, mesic Cumulic Hapludolls	GPS LOCATION: 457,893 E, 4,596,795 N
MAPPED SOIL SERIES: 96 - Turlin	DATE SAMPLED: May 2015 DATE DESCRIBED: June 2015
EPIPEDON: Umbric (97 cm)	SAMPLED BY: E.M. Dahlhauser DESCRIBED BY: E.M. Dahlhauser
SUBSURFACE HORIZONS/FEATURES: Cambic	CORE LENGTH: 147cm CORE DIAMETER: 63mm

					Texture				Structure				Coatings		Roots		Pores				Redox Features / Other			
Horizon	Horizon	Lower Depth (cm)	Bdry	Color (moist)	Class	% Clay	% Sand	% CF	Grade	Shape	Size	Consist. (moist)	Type	Amt	Amt	Size	Amt	Size	Eff.	pH (H2O)	Type	Color	Amt	Size
1	Ap1	9	A	10YR 2/2	L	21.3	44.5	0.00	1	sbk	vf	fr	-	-	f	vf-f	f	vf	-	5.25	-	-	-	-
2	Ap2	22	C	10YR 2/1	L	23.7	44.9	0.00	1	sbk	f	fr	-	-	f	vf-f	c	vf-f	-	4.86	-	-	-	-
3	A	55	G	10YR 2/1	SCL	22.1	54.0	0.01	2	sbk	m	fr	-	-	c	vf-f	m	vf-m	-	4.87	-	-	-	-
4	AB	78	G	10 YR 2/1 to 10YR 2/2	SCL	20.9	58.6	0.00	1 to 1	sbk gr	f f	fr	-	-	m	vf-f	m	vf-m	-	5.15	-	-	-	-
5	Bw	97	G	10YR 3/2	SL	18.0	68.7	0.02	1	sbk	m	fr	-	-	c	vf-f	m	vf-f	-	5.19	-	-	-	-
6	2C	147+	-	10YR 4/4 & band 10YR3/2	LS	9.4	87.1	1.80	0	sgr		loose	-	-	-	-	-	-	-	5.42	4 prominent dark lamellae	10YR 3/2		-

Notes:

*No stones on surface. Sandy lower portion.

*In the 6th horizon, dark colored lamellae present. 4 prominent lamellae: 104-107cm, 125-128cm, 130-131cm, and 135-139cm. They may be associated with a greater concentration of coarse frags.

They are possibly the site of the accumulation of solubilized organic matter.

Table 23. Profile description for A3B.

PROFILE: Avon Lake 3B	VEGETATION: Row crops (no-till soybeans)
PROFILE CLASSIFICATION: Fine-loamy over sandy, mixed, superactive, mesic Cumulic Hapludoll	SLOPE POSITION: 0.5% Footslope
PROFILE SOIL SERIES: Fort Dodge	COUNTY: Polk
MAPPED CLASSIFICATION: Fine loamy over sandy, mixed, superactive, mesic Typic Hapludolls	GPS LOCATION: 457,757 E, 4,596,720 N
MAPPED SOIL SERIES: 108 - Wadena	DATE SAMPLED: May 2015 DATE DESCRIBED: June 18, 2015
EPIPEDON: Umbric (106 cm)	SAMPLED BY: E.M. Dahlhauser DESCRIBED BY: E.M. Dahlhauser
SUBSURFACE HORIZONS/FEATURES: Cambic	CORE LENGTH: 147cm CORE DIAMETER: 63mm

					Texture				Structure				Coatings		Roots		Pores				Redox Features / Other			
Horizon	Horizon	Lower Depth (cm)	Bdry	Color (moist)	Class	% Clay	% Sand	% CF	Grade	Shape	Size	Consist. (moist)	Type	Amt	Amt	Size	Amt	Size	Eff.	pH (H2O)	Type	Color	Amt	Size
1	Ap1	13	C	10YR 2/1 to 10YR 3/1	L	21.0	31.7	0.12	1	sbk	f	fr	-	-	c	vf-f	c	vf-f	-	4.99	-	-	-	-
2	Ap2	27	C	10YR 2/1	L	23.6	29.7	0.02	2	sbk	m	fr	-	-	c	vf-f	c	vf-f	-	4.51	-	-	-	-
3	A	51	G	10YR 2/1	L	20.3	48.5	0.02	2 2	sbk gr	c f	fr	-	-	c	vf-f	m	vf-f	-	4.86	-	-	-	-
4	BA	77	C	10YR 2/2	SL	19.1	55.1	0.06	2	sbk	c	fr	-	-	f	vf	m	vf-f	-	5.00	-	-	-	-
5	2Bw	95	C	10YR 3/2	SL	16.6	66.6	1.29	2	sbk	m	fr	-	-	f	vf	m	vf	-	5.05	-	-	-	-
6	2BC	106	C	10YR 3/3	LS	10.6	81.4	14.09	1	sbk	m	fr	-	-	f	vf	m	vf	-	5.18	-	-	-	-
7	2C	147+	-	10YR 4/4	S	5.8	92.8	4.51	0	sgr		loose	-	-	-	-	-	-	-	5.35	-	-	-	-

Notes:

*Probed to 152cm depth.

*No stones on surface.

*In the 2nd horizon of the companion core Avon Lake 3A, at 23cm depth, found a piece of metal.

*In the 6th horizon, active breakdown of some coarse frags.

*The 7th horizon is comprised of carbonate-leached outwash. Lamellae of sediments with differing properties. 106-111cm has more coarse frags and more coarse sand, 111-124cm is mostly fine to medium sand with few coarse frags, 124-139cm is slightly brighter in color (but still 10YR 4/4) and has medium to coarse sand and more coarse frags, 139-147cm is fine to medium sand with few coarse frags.

Table 24. Profile description for A4A.

PROFILE: Avon Lake 4A	VEGETATION: Row crops (no-till soybeans)
PROFILE CLASSIFICATION: Fine-loamy over sandy, mixed, superactive, mesic Cumulic Hapludoll	SLOPE POSITION: 0.5% Footslope
PROFILE SOIL SERIES: Fort Dodge	COUNTY: Polk
MAPPED CLASSIFICATION: Fine loamy over sandy, mixed, superactive, mesic Typic Hapludolls	GPS LOCATION: 457,741 E, 4,596,854 N
MAPPED SOIL SERIES: 108 - Wadena	DATE SAMPLED: May 2015 DATE DESCRIBED: June 2015
EPIPEDON: Umbric (98 cm)	SAMPLED BY: E.M. Dahlhauser DESCRIBED BY: E.M. Dahlhauser
SUBSURFACE HORIZONS/FEATURES:	CORE LENGTH: 148cm CORE DIAMETER: 63mm

					Texture				Structure				Coatings		Roots		Pores				Redox Features / Other			
Horizon	Horizon	Lower Depth (cm)	Bdry	Color (moist)	Class	% Clay	% Sand	% CF	Grade	Shape	Size	Consist. (moist)	Type	Amt	Amt	Size	Amt	Size	Eff.	pH (H2O)	Type	Color	Amt	Size
1	Ap	11	C	10YR 2/1	L	20.3	39.2	0.31	1	sbk	vf-f	fr	-	-	c	vf	c	vf	-	5.23	-	-	-	-
2	A1	51	G	10YR 2/1	L	26.7	37.9	0.12	2	sbk	f	fr	-	-	c	vf	m	vf	-	4.94	-	-	-	-
3	A2	76	C	10YR 2/2	L	26.1	43.7	0.28	2	sbk	f-m	fr	-	-	c	vf	m	vf	-	5.11	-	-	-	-
4	2AB	98	G	10YR 3/2 to 10YR 3/3	G-SL	14.6	79.5	17.68	2	sbk	f-m	fr	-	-	c	vf	c	vf	-	5.27	ghosts	-	-	-
5	2BC	131	C	10YR 3/6	G-LS	10.6	86.7	18.81	1	sbk	f	vfr	-	-	f	vf	f	vf	-	5.35	-	-	-	-
6	3C	148+	-	10YR 4/4	S	6.9	91.2	0.34	0	sgr		loose	-	-	-	-	-	-	-	5.34	-	-	-	-

Notes:

*Probed to 152cm. Removed 140cm from probe. Some compaction.

*No stones found on surface at site.

*In the 3rd horizon, some coarse sand present.

*In the 4th horizon, weathered granite frag.

*In the 5th horizon, a relatively unweathered granite frag, but also smaller weathered granite frags.

*In 5th horizon, 112cm to 122cm interval is sand with few coarse frags.

*The lowest 2 horizons are comprised of mostly sand and are clearly compacted from probing.

*In 6th horizon, called a 3rd parent material due to lack of particles larger than coarse sand. You could still argue that it is part of the 2nd parent material. (Labeling of different parent materials is often controlled by a large increase/decrease in sand and/or coarse frags in many of these profile descriptions.

Table 25. Profile description for A5A.

PROFILE: Avon Lake 5A	VEGETATION: Row crops (no-till soybeans)
PROFILE CLASSIFICATION: Fine-loamy over sandy, mixed, superactive, mesic Cumulic Hapludoll	SLOPE POSITION: 0.5% Footslope
PROFILE SOIL SERIES: Fort Dodge	COUNTY: Polk
MAPPED CLASSIFICATION: Fine, smectitic, mesic Typic Argiaquolls	GPS LOCATION: 457,741 E, 4,596,976 N
MAPPED SOIL SERIES: 43 - Bremer	DATE SAMPLED: May 2015 DATE DESCRIBED: June 19, 2015
EPIPEDON: Umbric (95 cm)	SAMPLED BY: E.M. Dahlhauser DESCRIBED BY: E.M. Dahlhauser
SUBSURFACE HORIZONS/FEATURES: Cambic	CORE LENGTH: 138cm CORE DIAMETER: 63mm

		Lower			Texture				Structure				Coatings		Roots		Pores				Redox Features / Other			
Horizon	Horizon	Depth (cm)	Bdry	Color (moist)	Class	% Clay	% Sand	% CF	Grade	Shape	Size	Consist. (moist)	Type	Amt	Amt	Size	Amt	Size	Eff.	pH (H2O)	Type	Color	Amt	Size
1	Ap	19	C	10YR 3/2	L	23.1	28.9	0.10	1	sbk	f	fr	-	-	f	vf	c	vf	-	4.62	-	-	-	-
2	A	50	G	10YR 2/1 to 10YR 2/2	L	22.7	46.1	0.03	1 1	sbk gr	m f	fr	-	-	f	vf-f	m	vf-f	-	5.00	-	-	-	-
3	AB	72	C	10YR 3/2	SL	18.7	57.0	0.09	1 1	sbk gr	m f	fr	-	-	f	vf-f	m	vf-f	-	5.21	-	-	-	-
4	2Bw	95	G	10YR 3/3	SL	15.0	70.2	3.08	1	sbk	f	fr	-	-	f	vf	m	vf	-	5.31	-	-	-	-
5	2C1	120	C	10YR 3/4	LS	6.8	88.2	11.63	0	sgr		loose	-	-	-	-	-	-	-	5.60	-	-	-	-
6	3C2	138+	-	10YR 4/4	S	5.9	91.1	2.21	0	sgr		loose	-	-	-	-	-	-	-	5.75	-	-	-	-

Notes:

*Probed to 153cm. Had 134cm in probe tube.

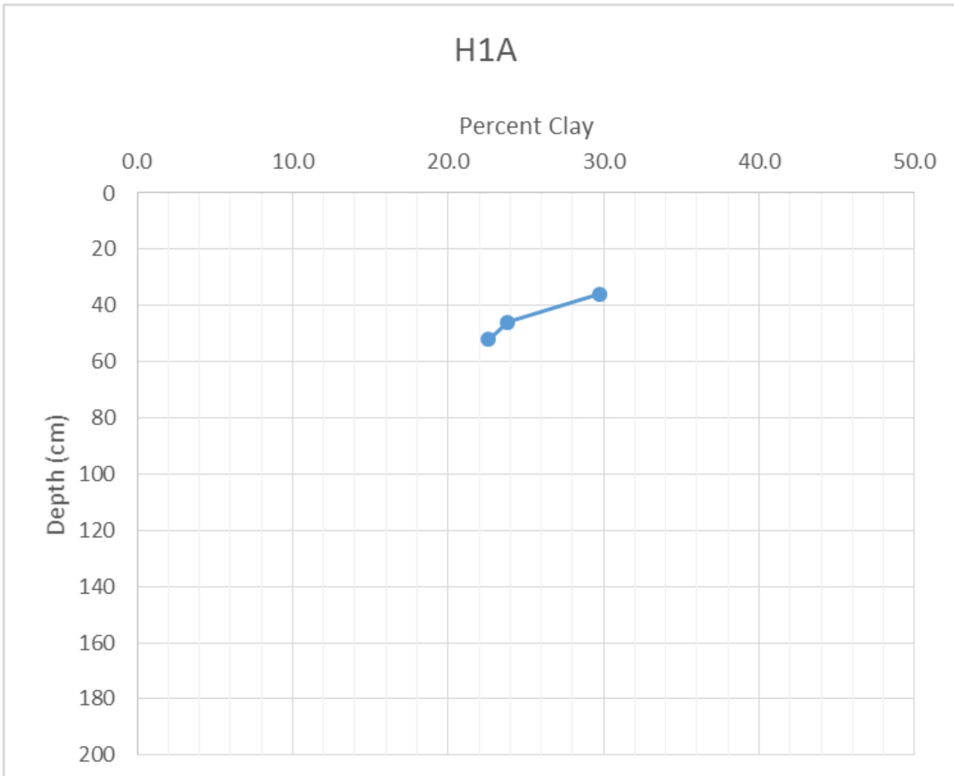
*No stones on surface. Sandy outwash observed in the lower half of profile.

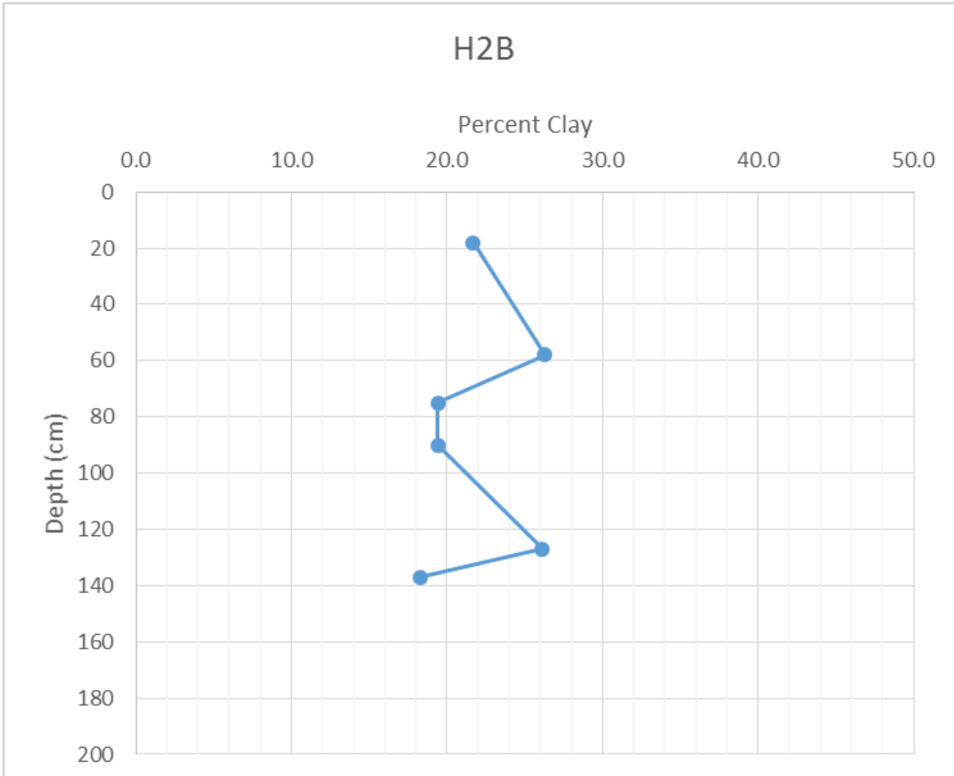
*In the 5th horizon, perhaps very weak structure 1 sbk m. No roots, but perhaps organic matter is responsible for darker colors. Any structures crumble upon picking up.

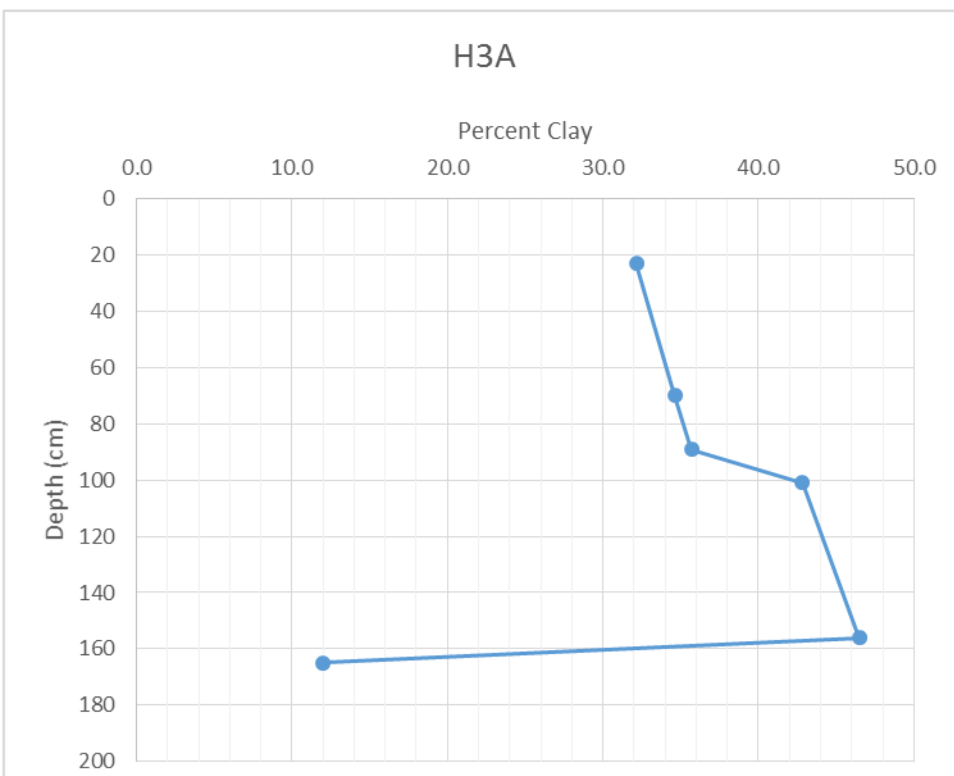
*A third parent material was called due to the drop in coarse frags and coarse sand.

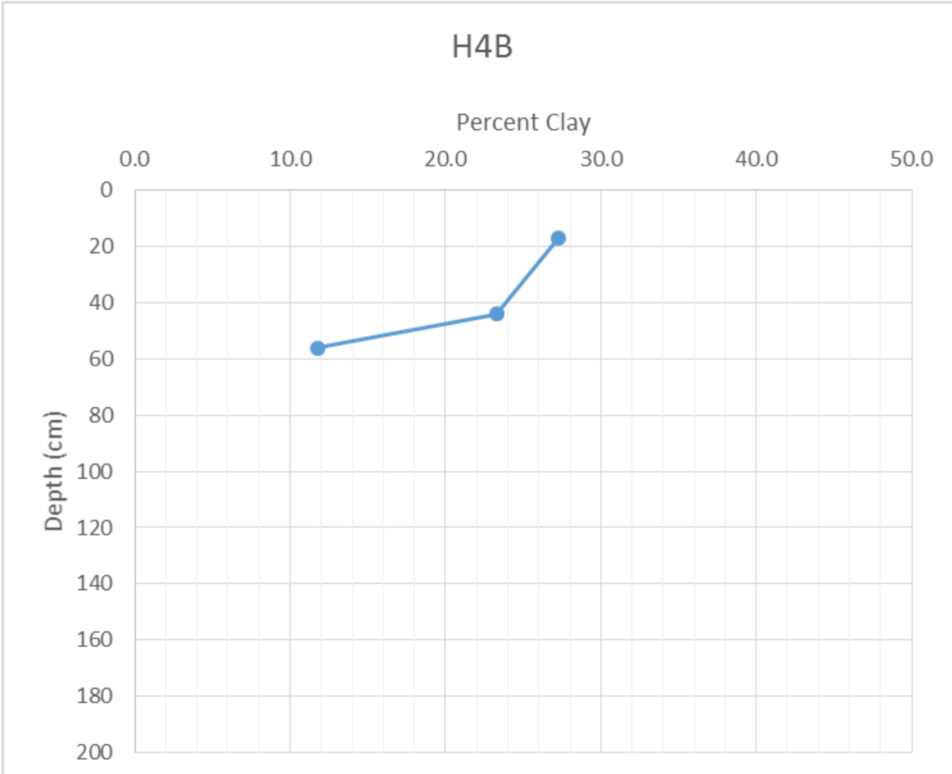
APPENDIX B

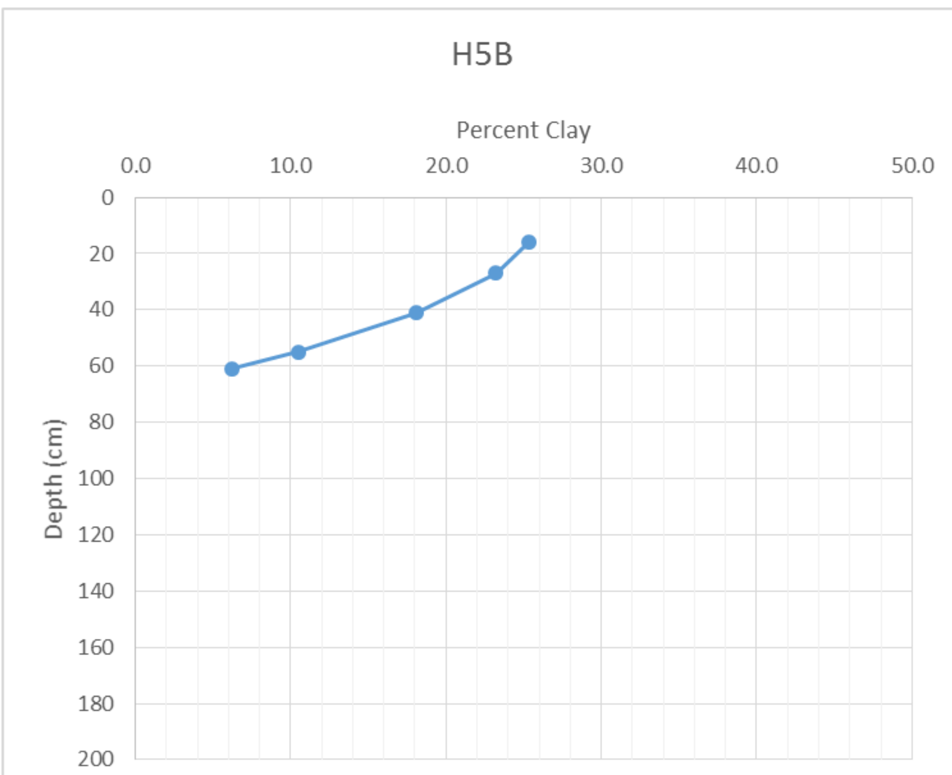
PLOTS OF PERCENT CLAY VS. DEPTH

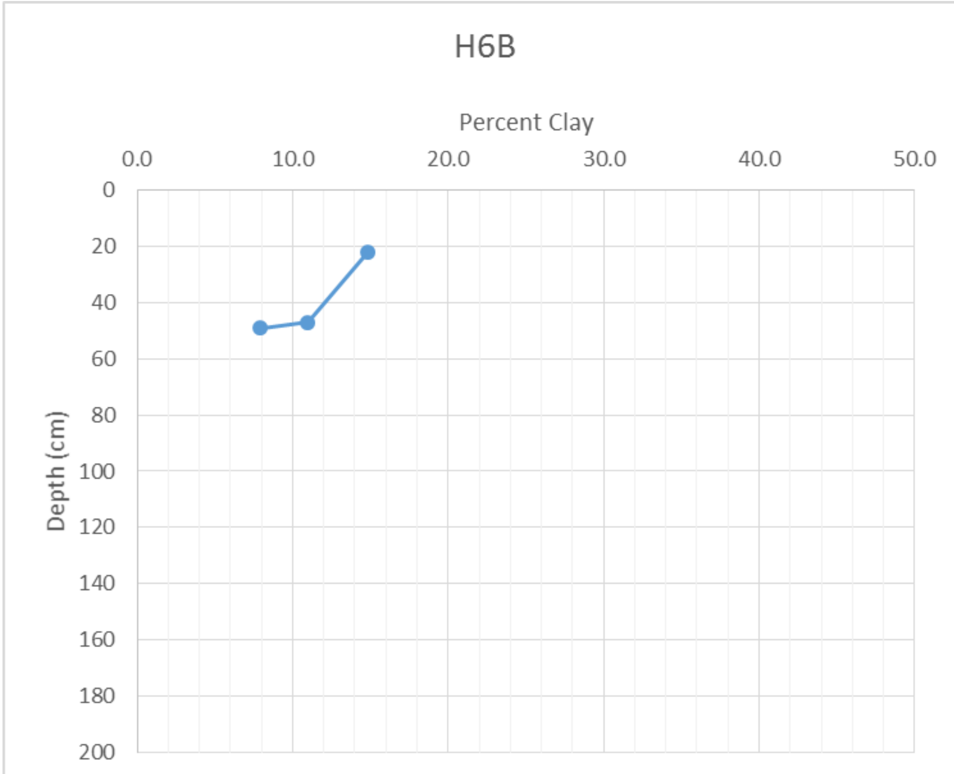


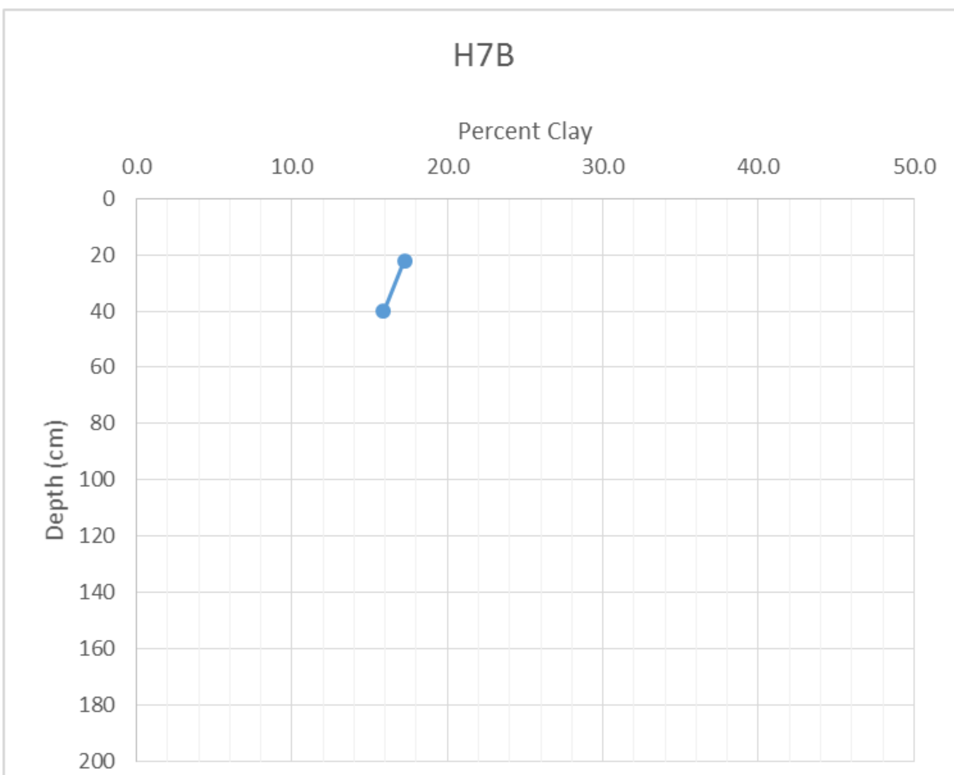

H2B
Percent Clay
0.0
10.0
20.0
30.0
40.0
50.0
Depth (cm)
0
20
40
60
80
100
120
140
160
180
200

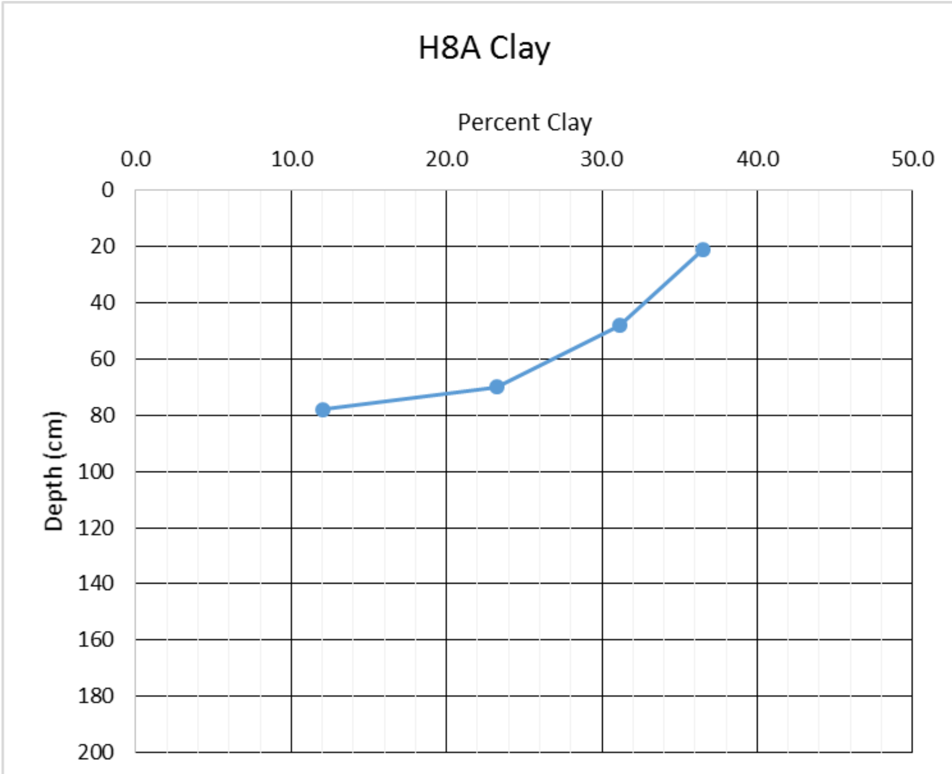

H3A
Percent Clay
0.0
10.0
20.0
30.0
40.0
50.0
Depth (cm)
0
20
40
60
80
100
120
140
160
180
200

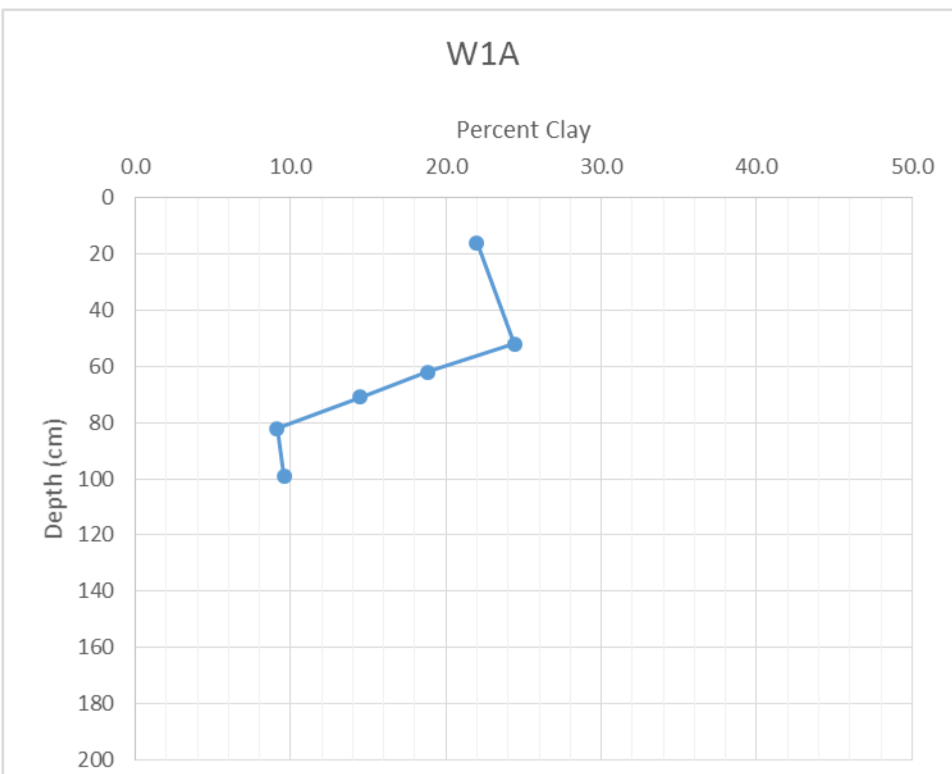

H4B
Percent Clay
0.0
10.0
20.0
30.0
40.0
50.0
Depth (cm)
0
20
40
60
80
100
120
140
160
180
200

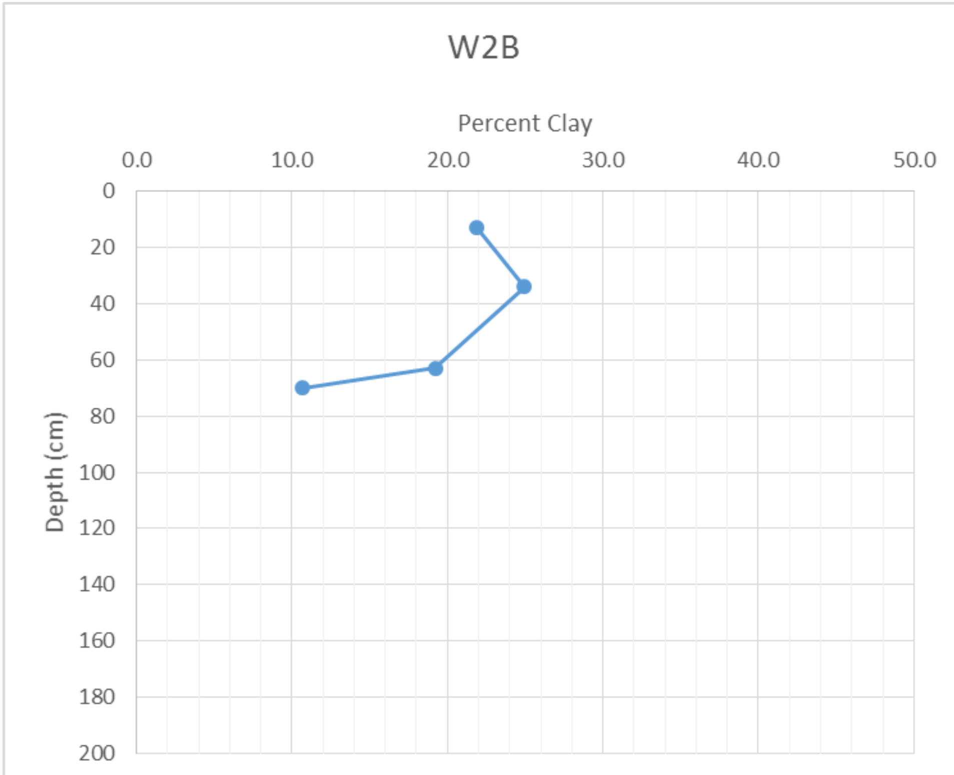

H5B
Percent Clay
0.0
10.0
20.0
30.0
40.0
50.0
Depth (cm)
0
20
40
60
80
100
120
140
160
180
200

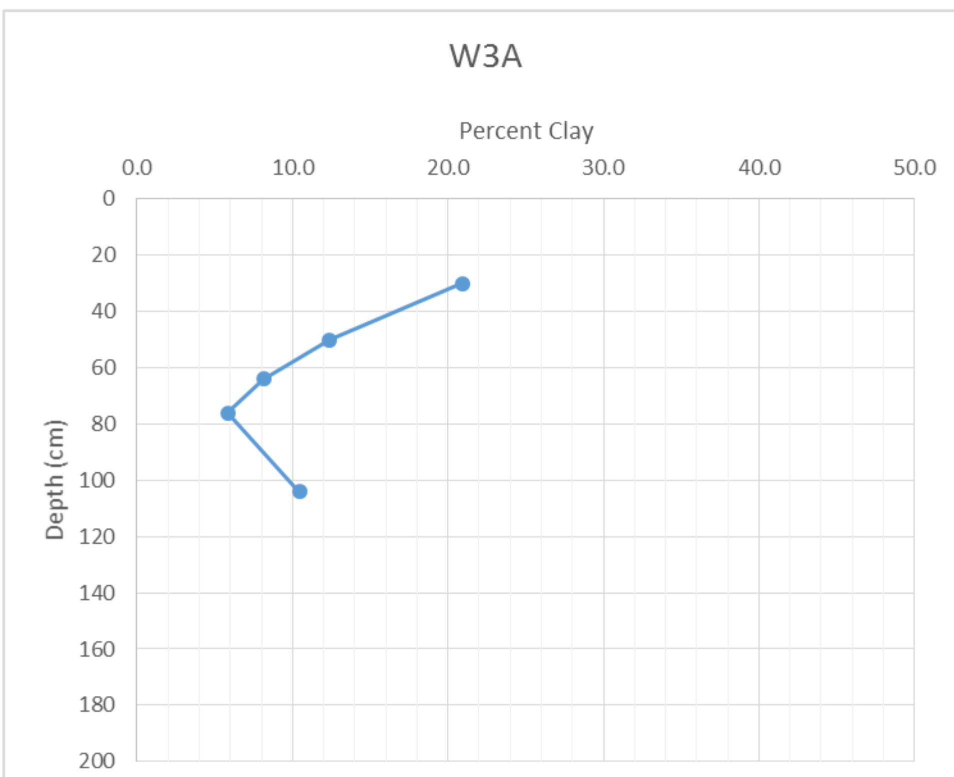

H6B
Percent Clay
0.0
10.0
20.0
30.0
40.0
50.0
Depth (cm)
0
20
40
60
80
100
120
140
160
180
200

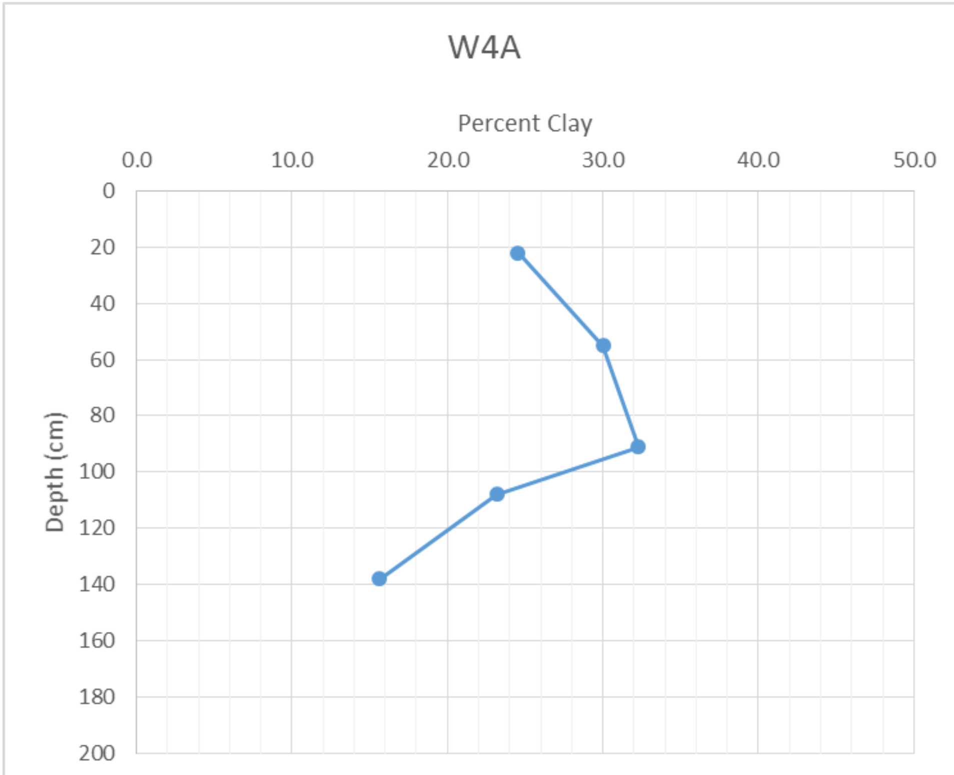

H7B
Percent Clay
0.0
10.0
20.0
30.0
40.0
50.0
Depth (cm)
0
20
40
60
80
100
120
140
160
180
200

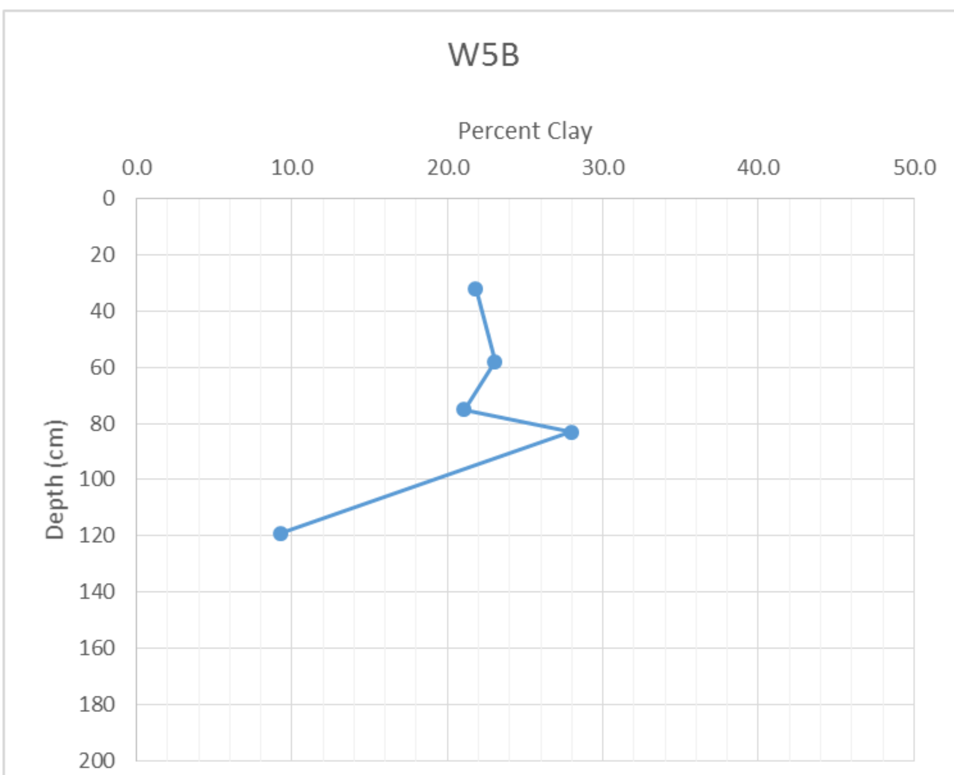

H8A Clay
Percent Clay
0.0
10.0
20.0
30.0
40.0
50.0
Depth (cm)
0
20
40
60
80
100
120
140
160
180
200

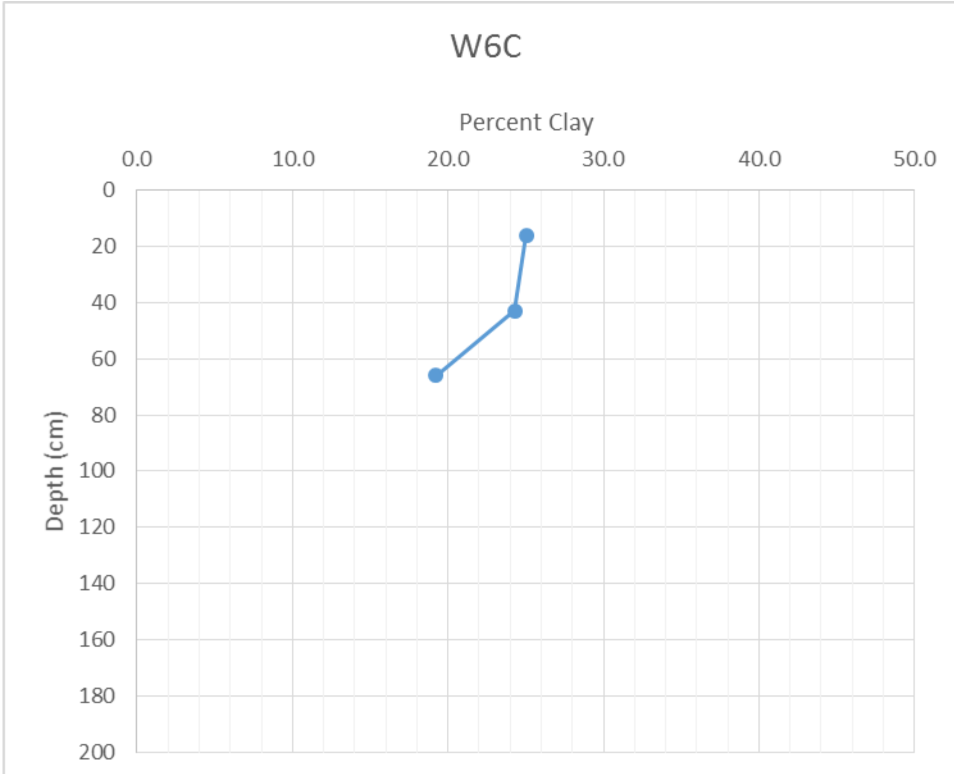

W1A
Percent Clay
0.0
10.0
20.0
30.0
40.0
50.0
Depth (cm)
0
20
40
60
80
100
120
140
160
180
200

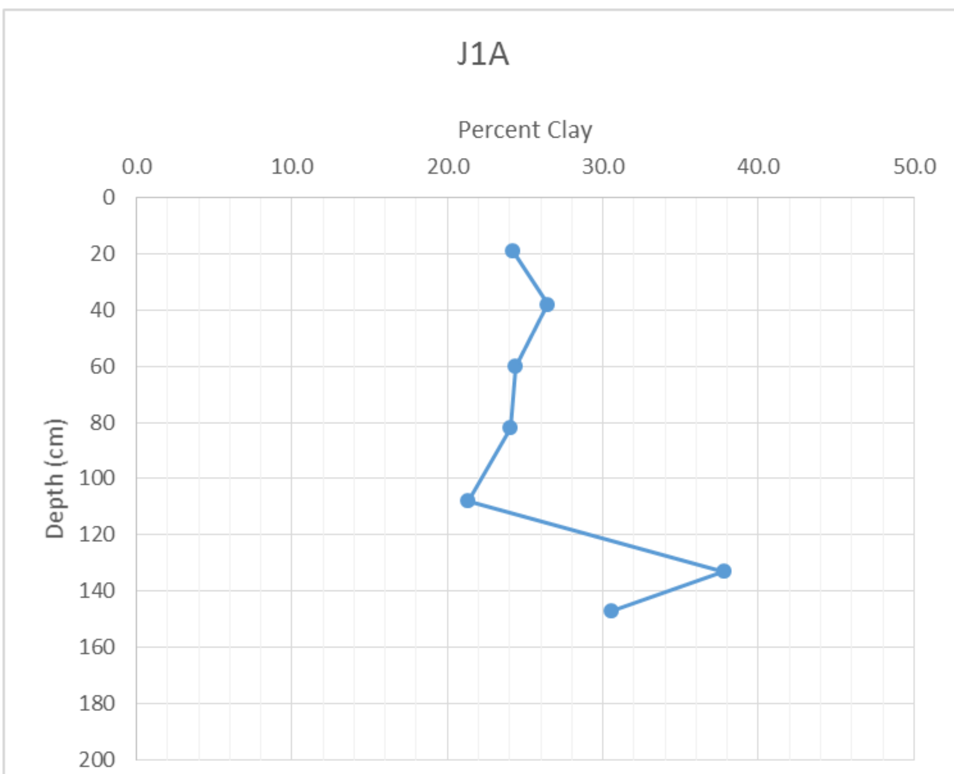

W2B
Percent Clay
0.0
10.0
20.0
30.0
40.0
50.0
Depth (cm)
0
20
40
60
80
100
120
140
160
180
200

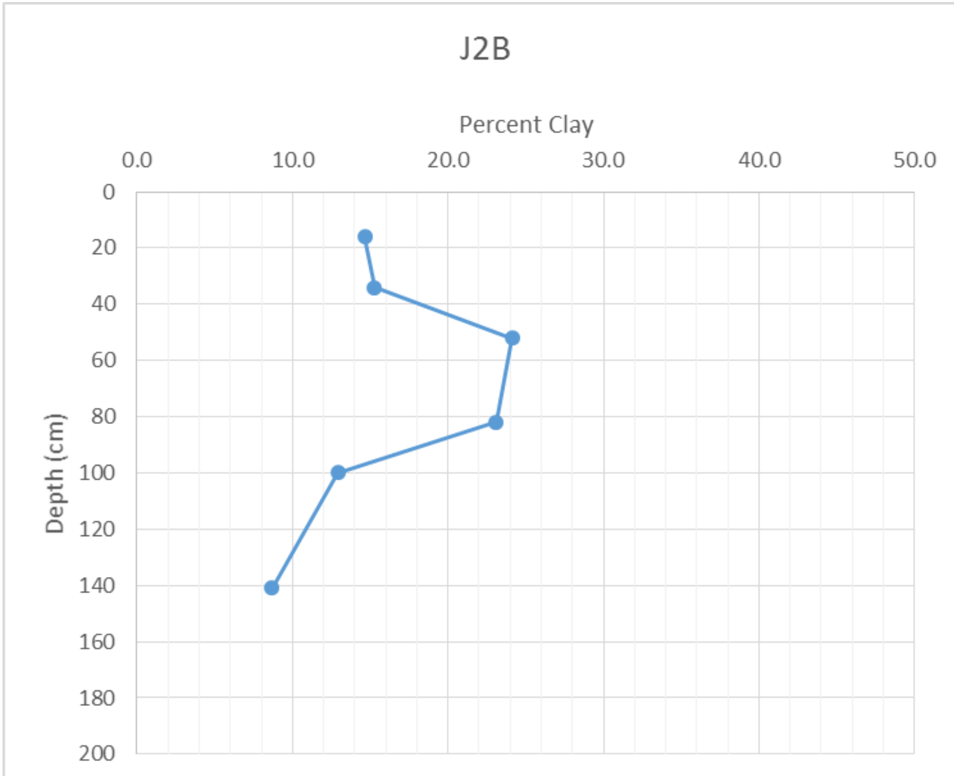

W3A
Percent Clay
0.0
10.0
20.0
30.0
40.0
50.0
Depth (cm)
0
20
40
60
80
100
120
140
160
180
200

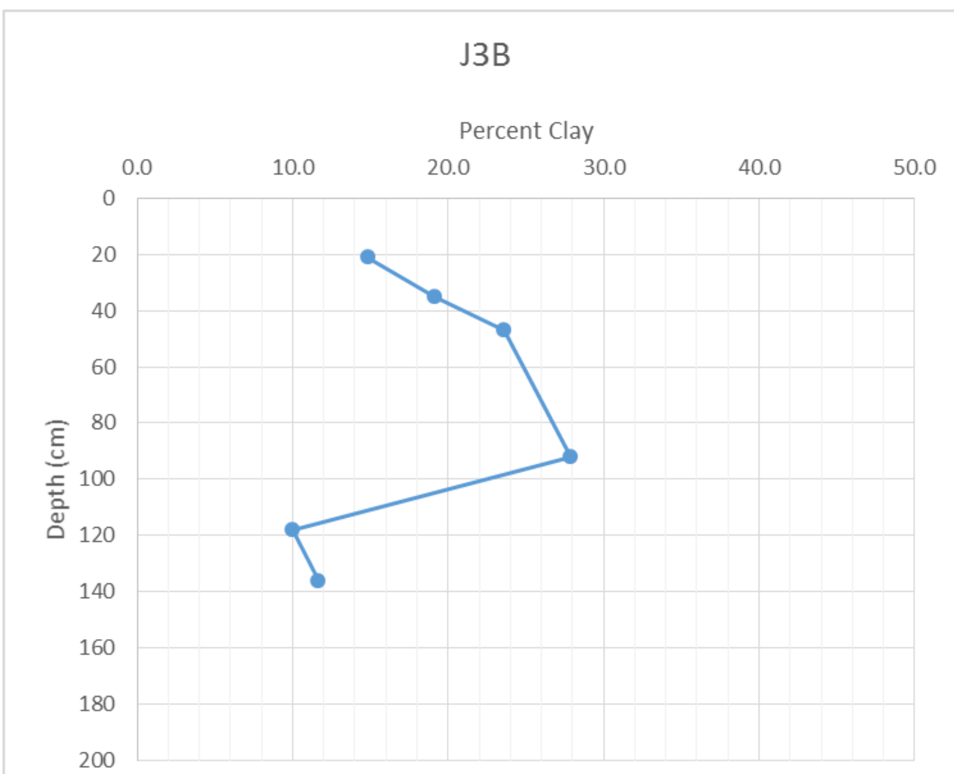

W4A
Percent Clay
0.0
10.0
20.0
30.0
40.0
50.0
Depth (cm)
0
20
40
60
80
100
120
140
160
180
200


W5B
Percent Clay
0.0
10.0
20.0
30.0
40.0
50.0
Depth (cm)
0
20
40
60
80
100
120
140
160
180
200

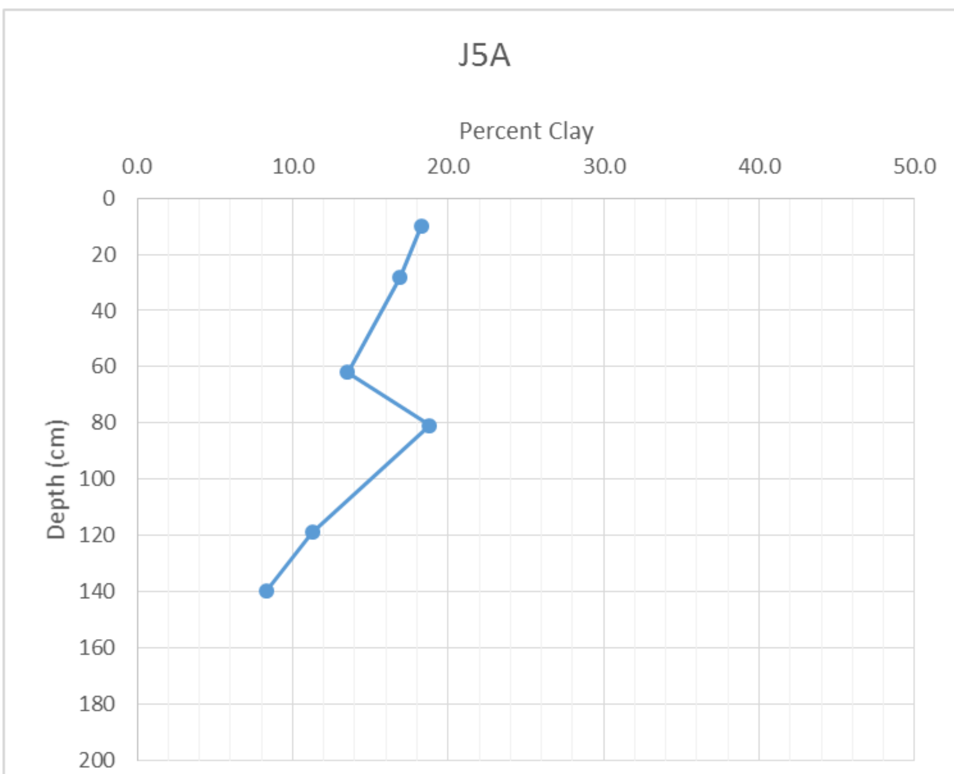

W6C
Percent Clay
0.0
10.0
20.0
30.0
40.0
50.0
Depth (cm)
0
20
40
60
80
100
120
140
160
180
200

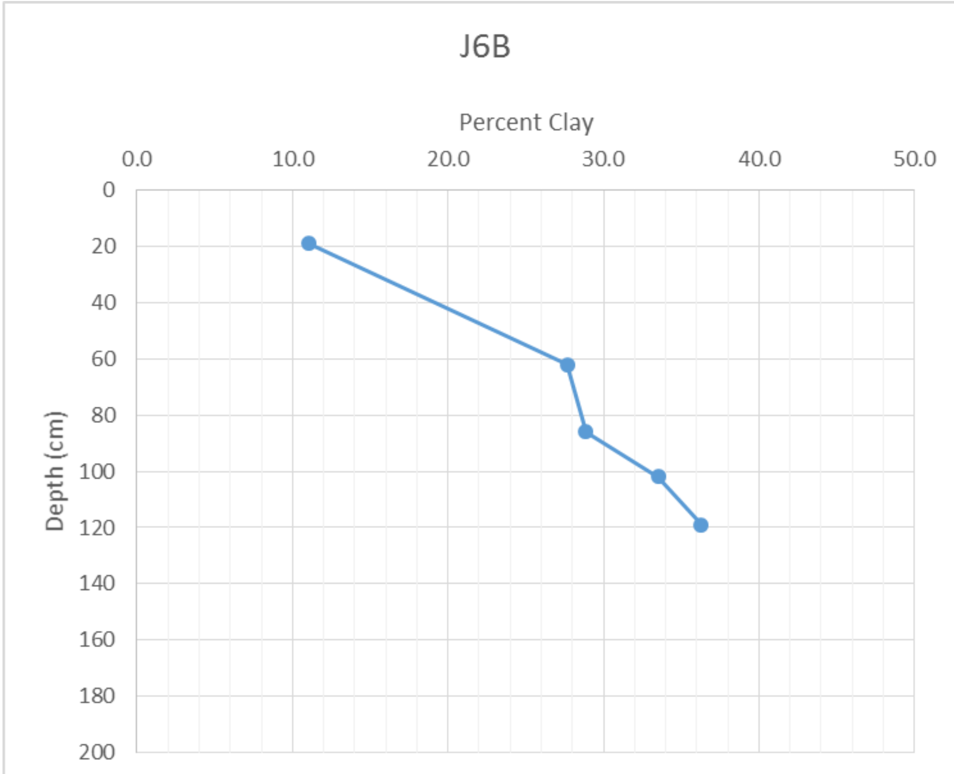

J1A
Percent Clay
0.0
10.0
20.0
30.0
40.0
50.0
Depth (cm)
0
20
40
60
80
100
120
140
160
180
200

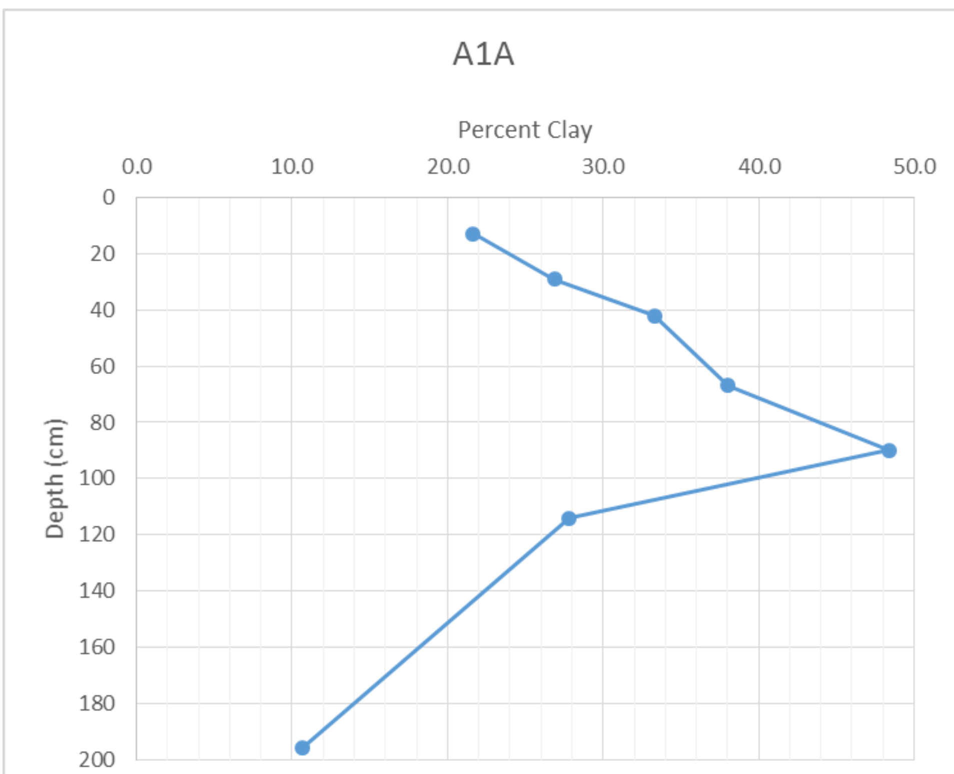

J2B
Percent Clay
0.0
10.0
20.0
30.0
40.0
50.0
0
20
40
60
80
100
120
140
160
180
200
Depth (cm)

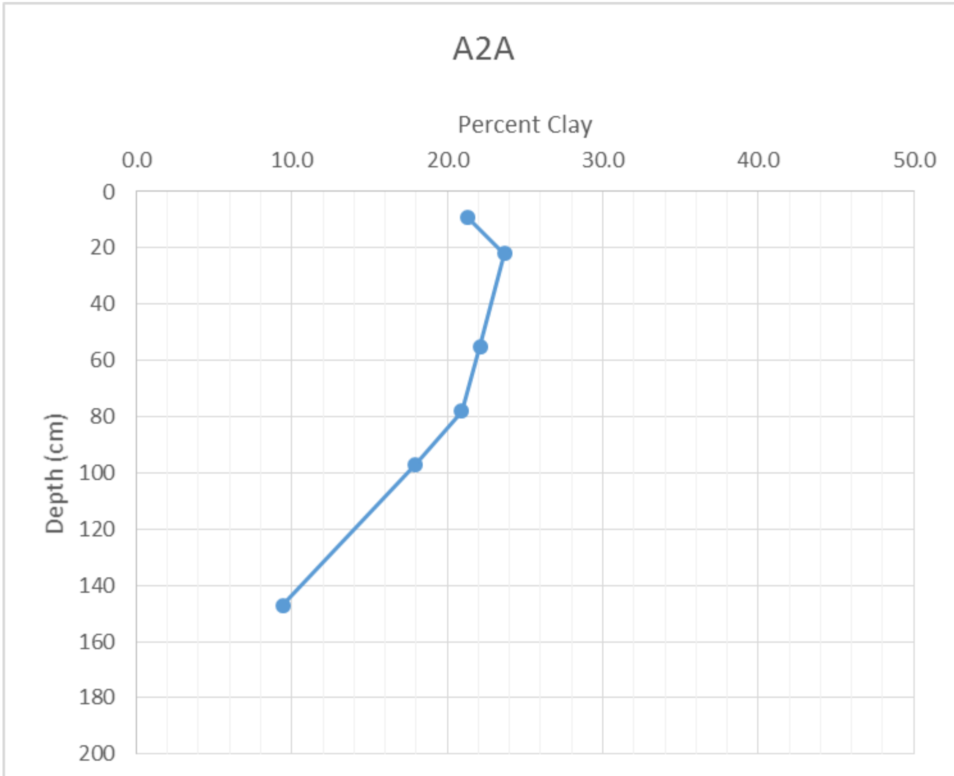

J3B
Percent Clay
0.0
10.0
20.0
30.0
40.0
50.0
0
20
40
60
80
100
120
140
160
180
200
Depth (cm)

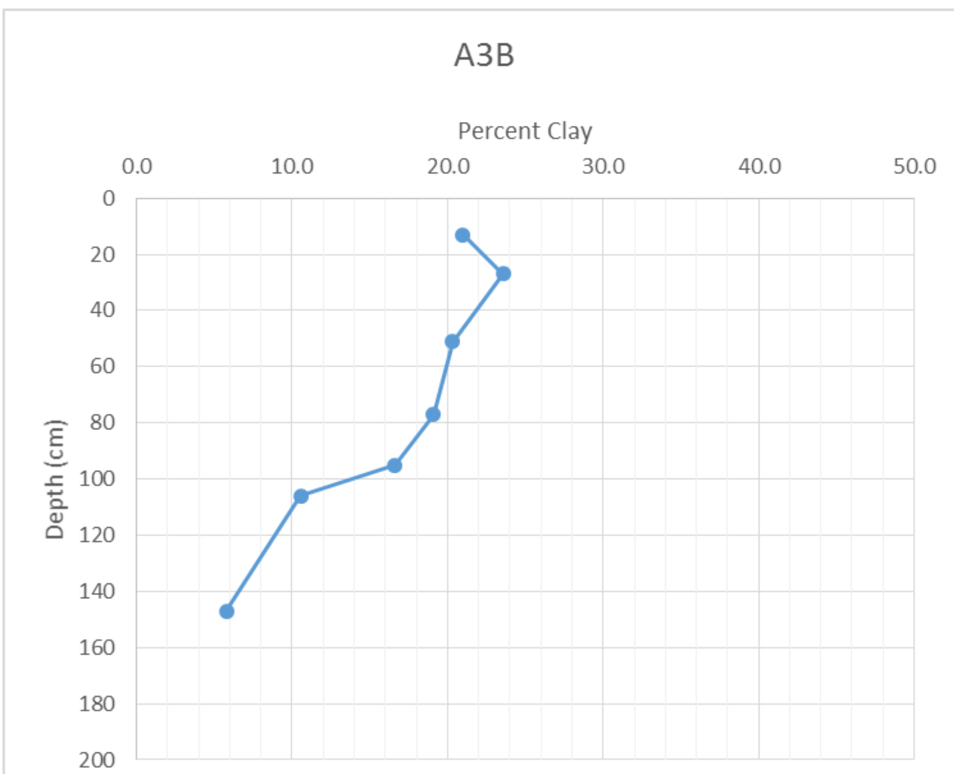

J4A
Percent Clay
0.0
10.0
20.0
30.0
40.0
50.0
Depth (cm)
0
20
40
60
80
100
120
140
160
180
200

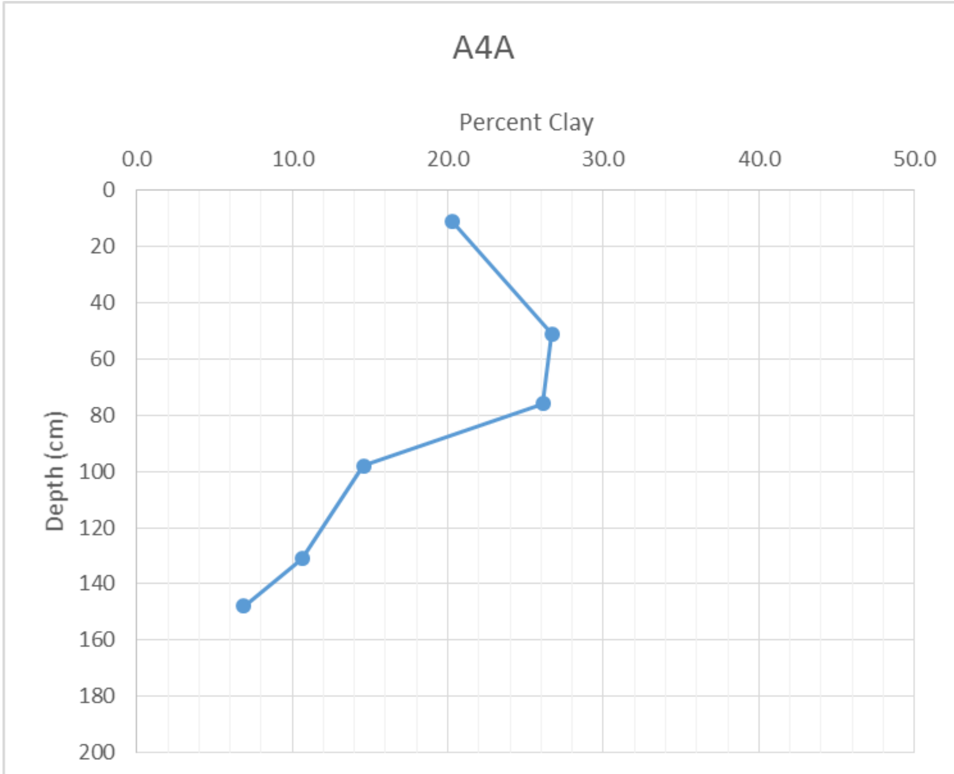

J5A
Percent Clay
0.0
10.0
20.0
30.0
40.0
50.0
Depth (cm)
0
20
40
60
80
100
120
140
160
180
200

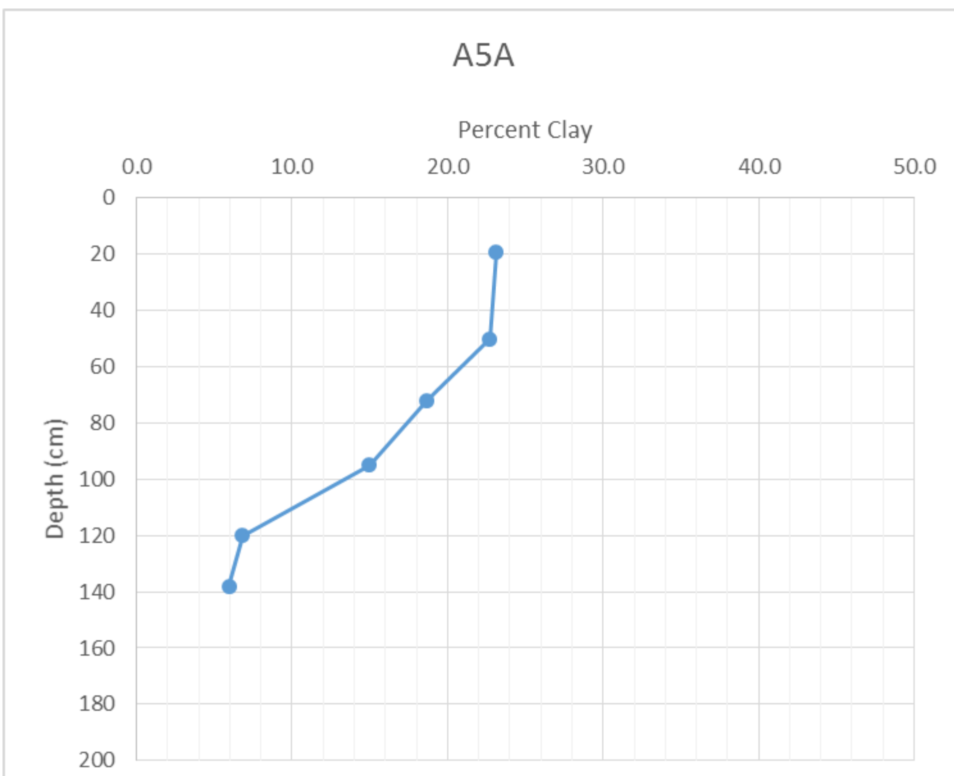

J6B
Percent Clay
0.0
10.0
20.0
30.0
40.0
50.0
Depth (cm)
0
20
40
60
80
100
120
140
160
180
200


A1A
Percent Clay
0.0
10.0
20.0
30.0
40.0
50.0
Depth (cm)
0
20
40
60
80
100
120
140
160
180
200


A2A
Percent Clay
0.0
10.0
20.0
30.0
40.0
50.0
Depth (cm)
0
20
40
60
80
100
120
140
160
180
200

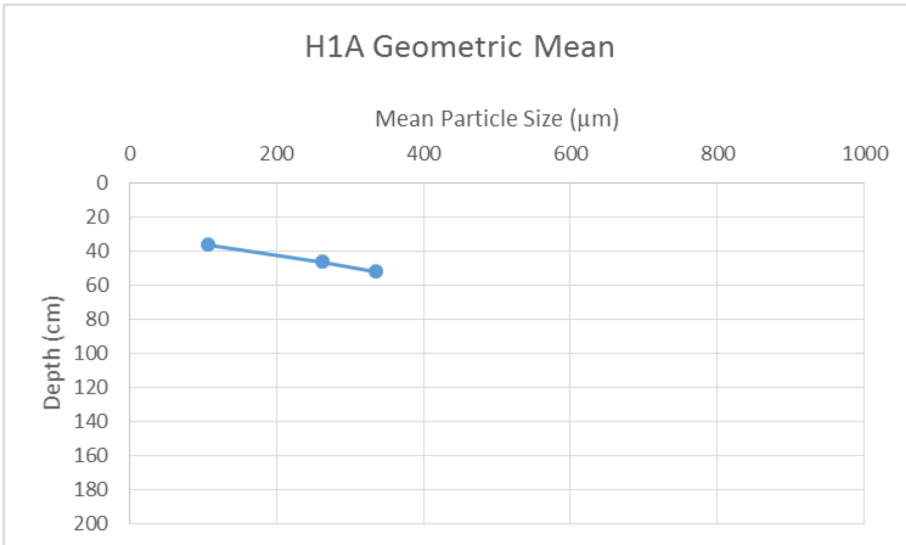

A3B
Percent Clay
0.0
10.0
20.0
30.0
40.0
50.0
Depth (cm)
0
20
40
60
80
100
120
140
160
180
200

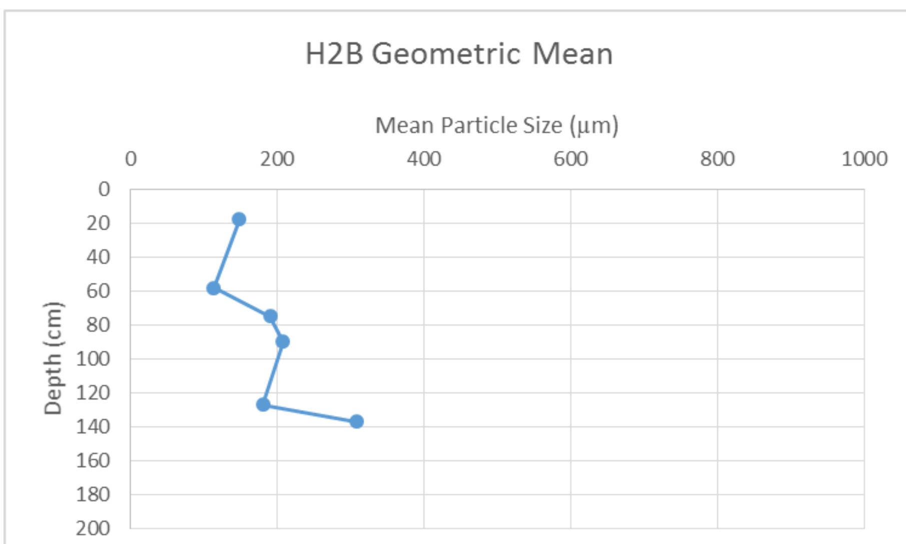

A4A
Percent Clay
0.0
10.0
20.0
30.0
40.0
50.0
Depth (cm)
0
20
40
60
80
100
120
140
160
180
200

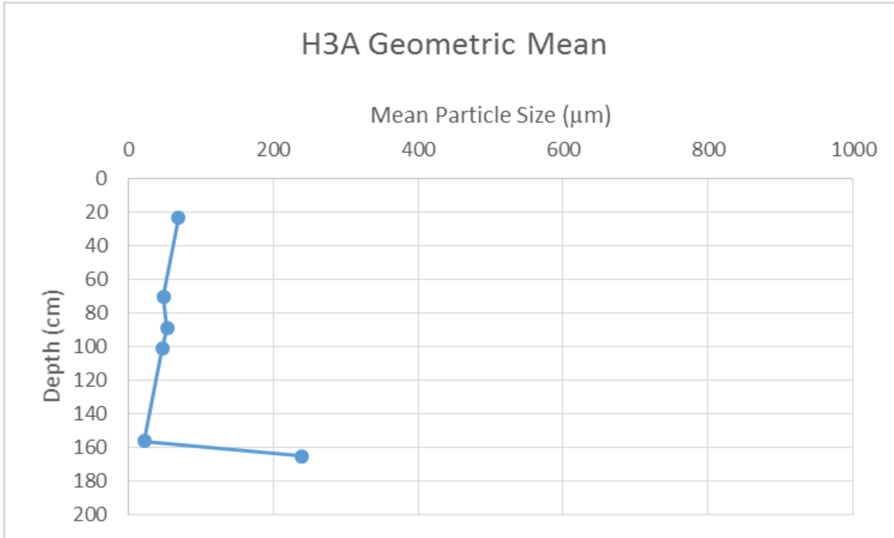

A5A
Percent Clay
0.0
10.0
20.0
30.0
40.0
50.0
Depth (cm)
0
20
40
60
80
100
120
140
160
180
200

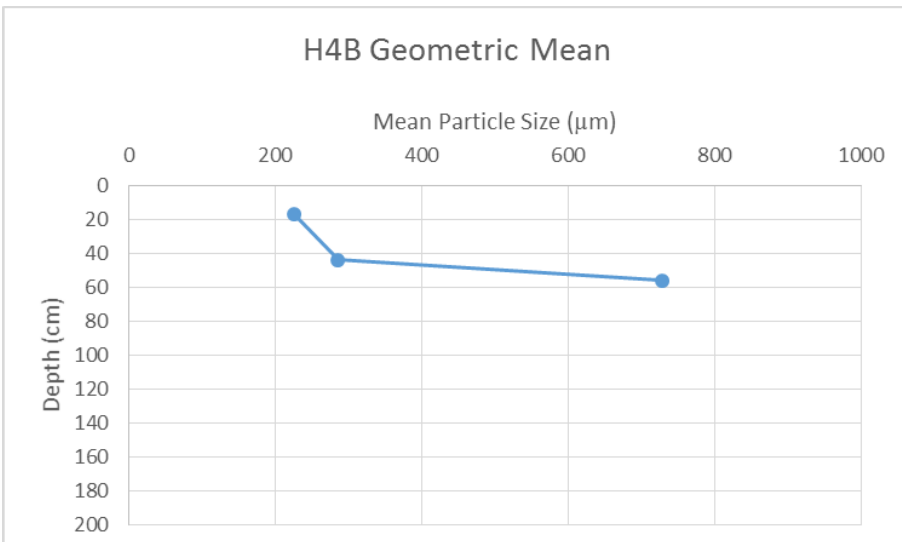
APPENDIX C

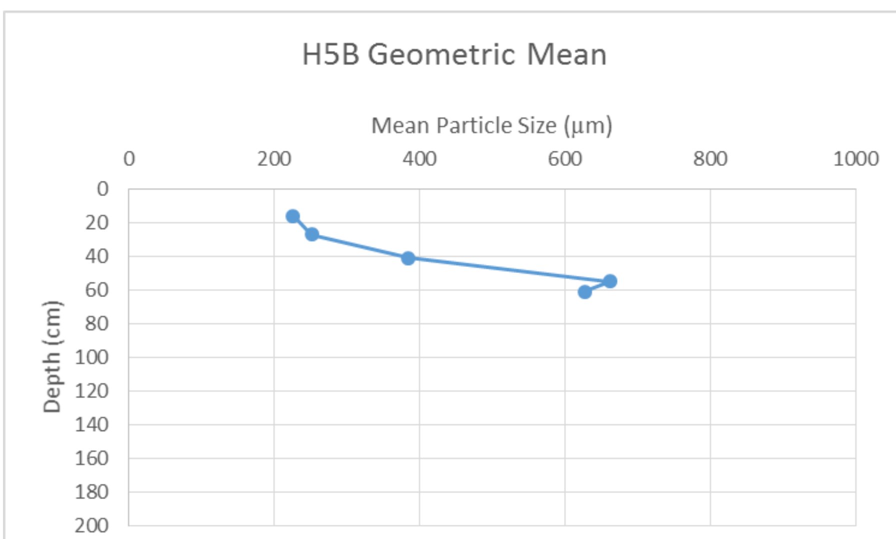
PLOTS OF GEOMETRIC MEANS VS. DEPTH

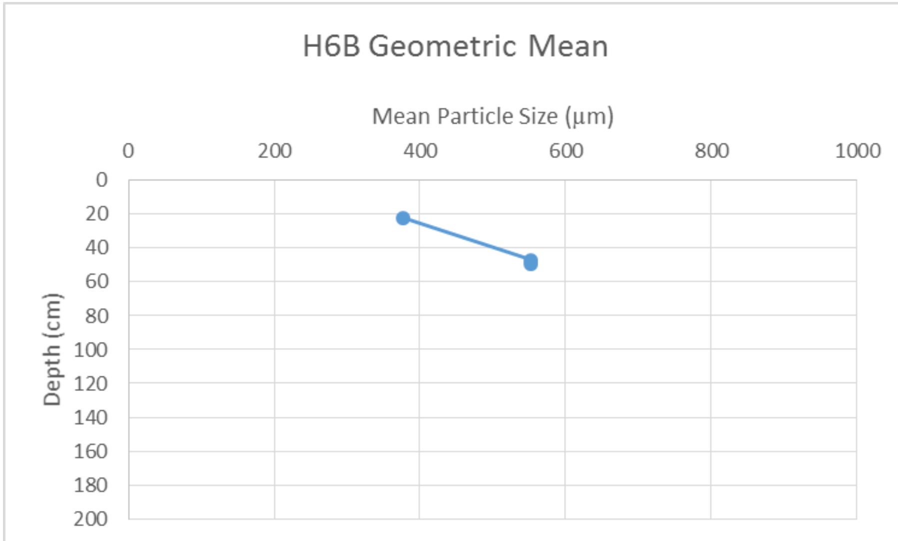


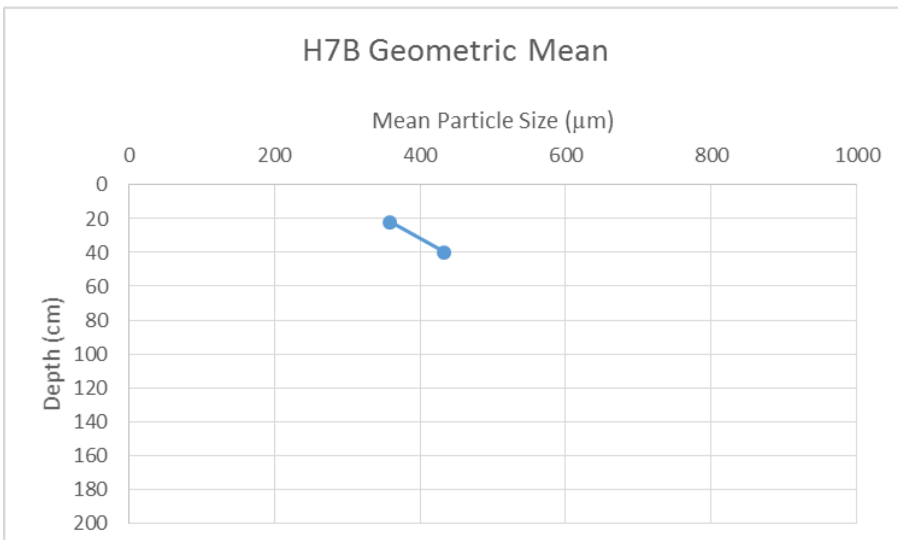



H3A Geometric Mean
Mean Particle Size (µm)
0
200
400
600
800
1000
Depth (cm)
0
20
40
60
80
100
120
140
160
180
200


H4B Geometric Mean
Mean Particle Size (µm)
0
200
400
600
800
1000
Depth (cm)
0
20
40
60
80
100
120
140
160
180
200


H5B Geometric Mean
Mean Particle Size (µm)
0
200
400
600
800
1000
Depth (cm)
0
20
40
60
80
100
120
140
160
180
200


H6B Geometric Mean
Mean Particle Size (µm)
0 200 400 600 800 1000
Depth (cm)
0 20 40 60 80 100 120 140 160 180 200


H7B Geometric Mean
Mean Particle Size (µm)
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Depth (cm)
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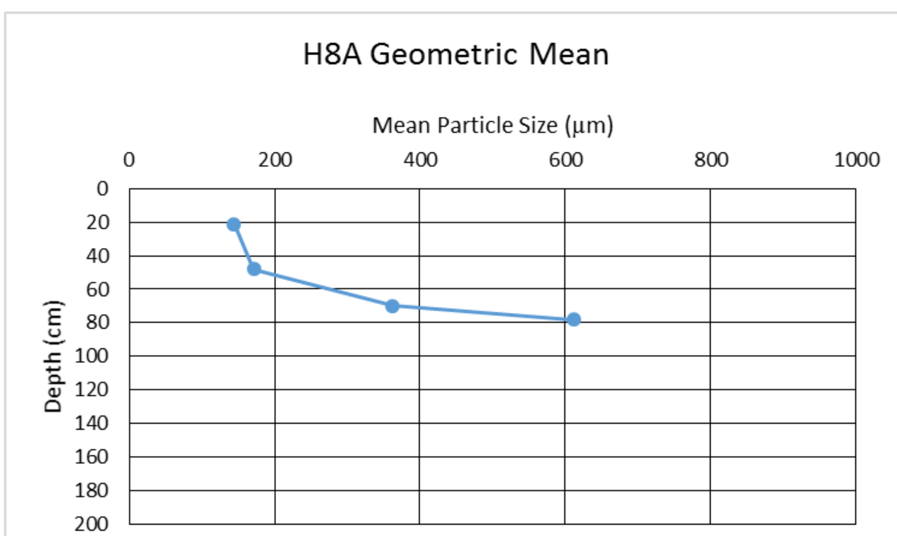
H8A Geometric Mean
Mean Particle Size (µm)
0 200 400 600 800 1000
Depth (cm)
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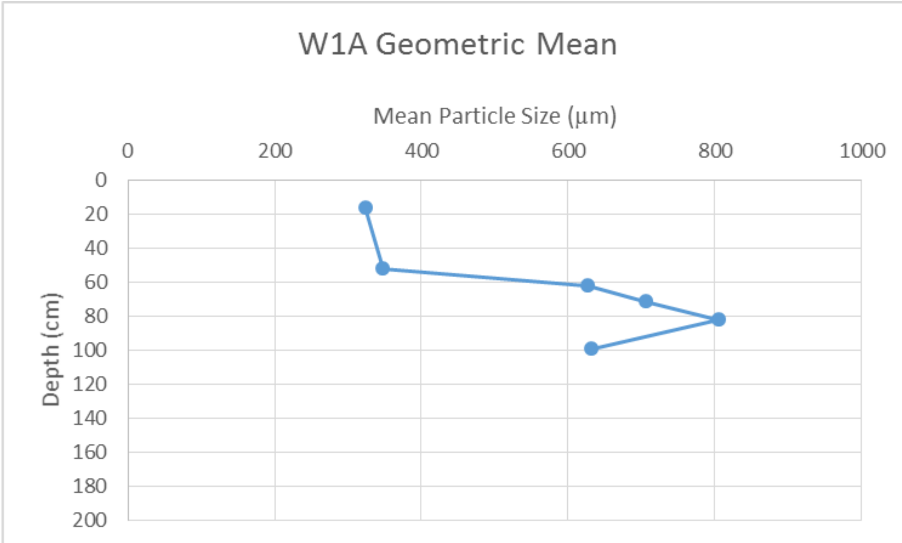
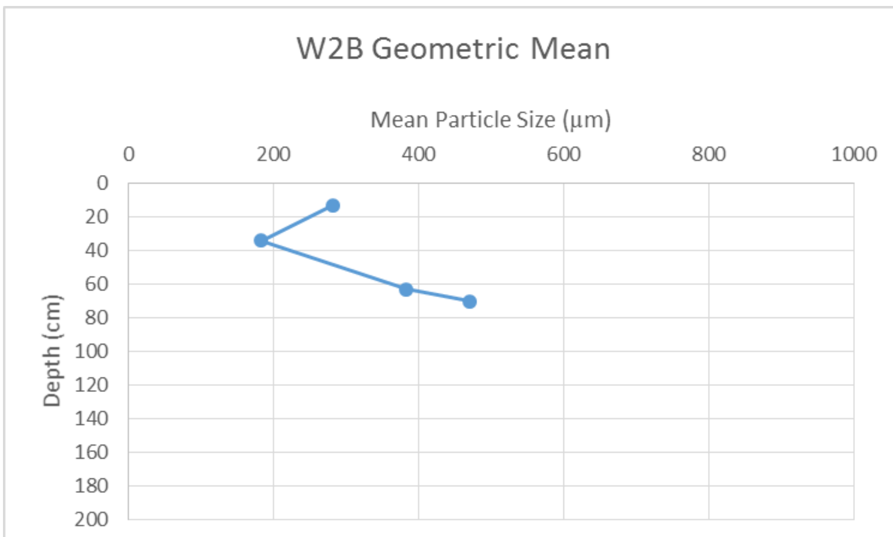
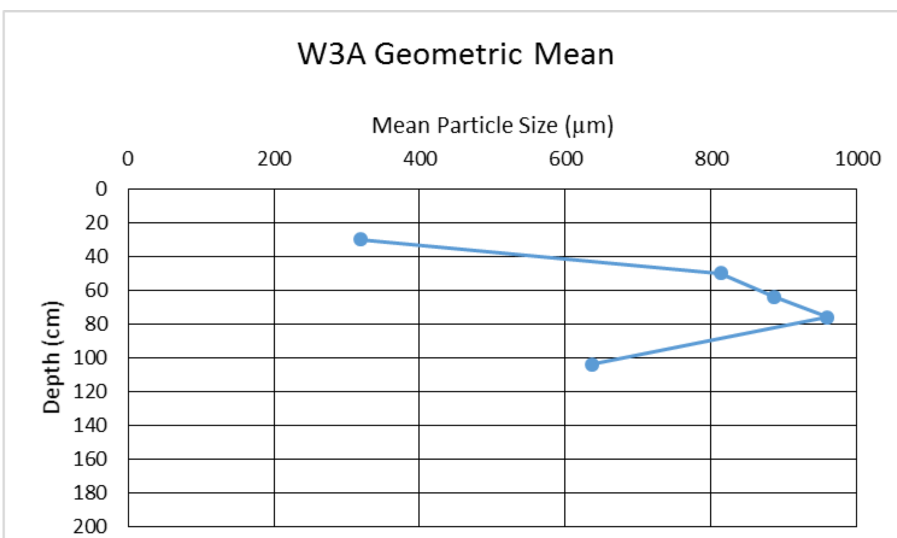

W1A Geometric Mean
Mean Particle Size (µm)
0
200
400
600
800
1000
Depth (cm)
0
20
40
60
80
100
120
140
160
180
200


W2B Geometric Mean
Mean Particle Size (µm)
0
200
400
600
800
1000
Depth (cm)
0
20
40
60
80
100
120
140
160
180
200


W3A Geometric Mean
Mean Particle Size (µm)
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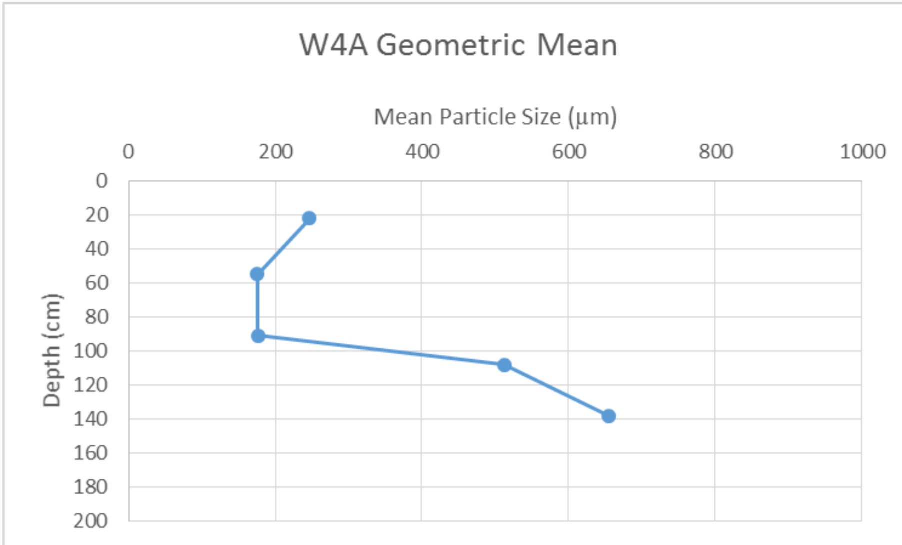
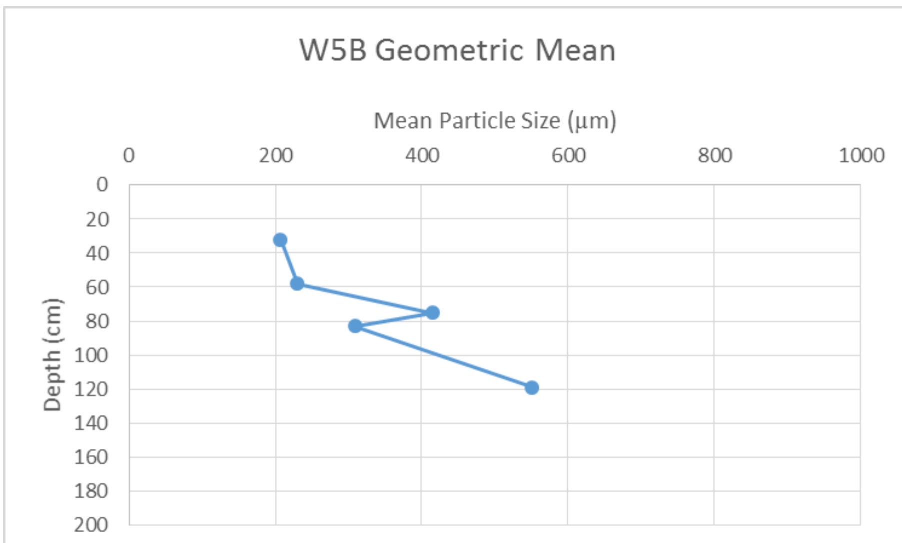
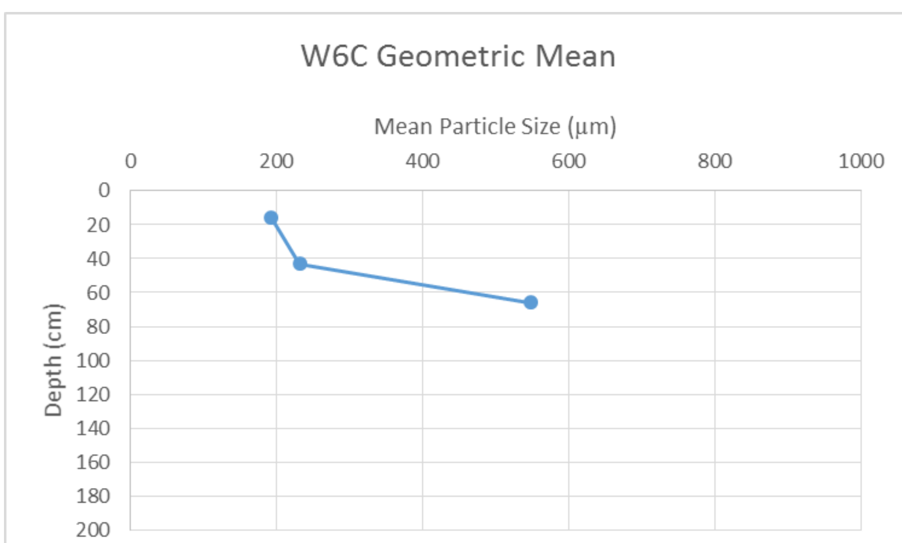
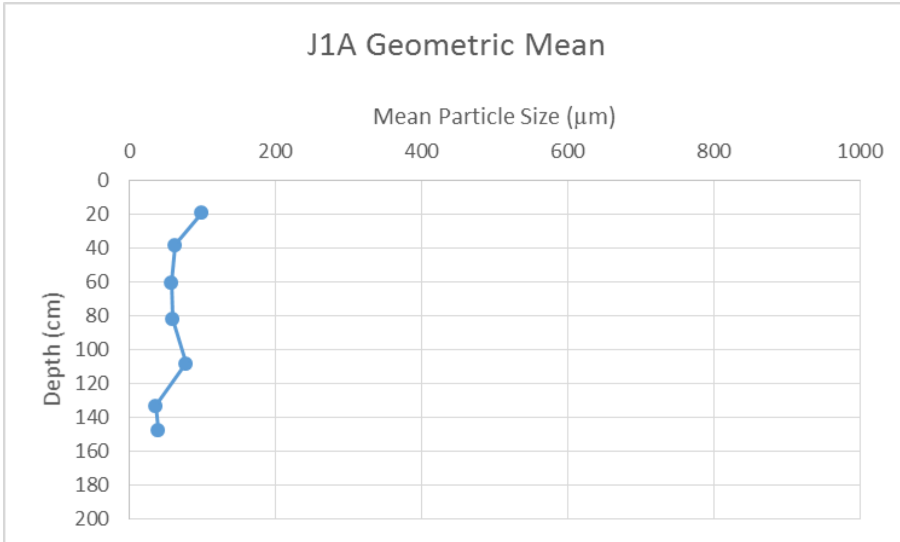
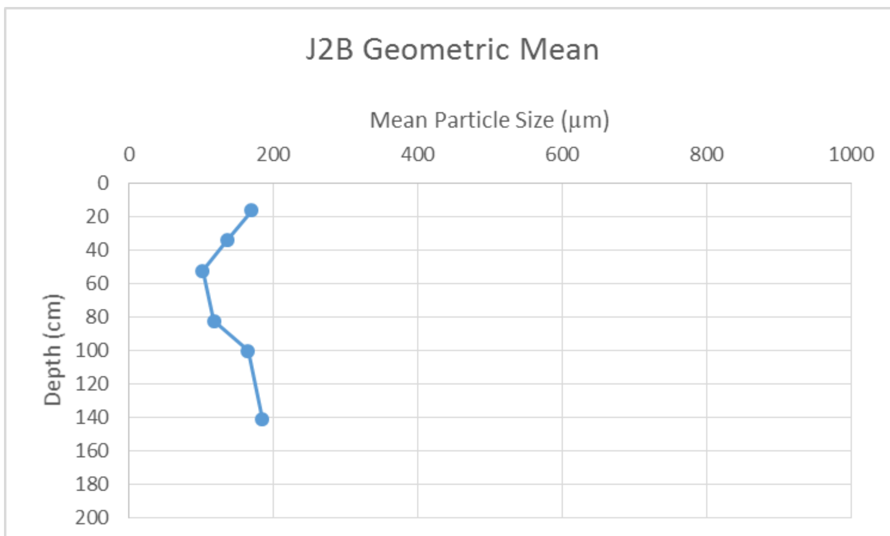
200
400
600
800
1000
Depth (cm)
0
20
40
60
80
100
120
140
160
180
200

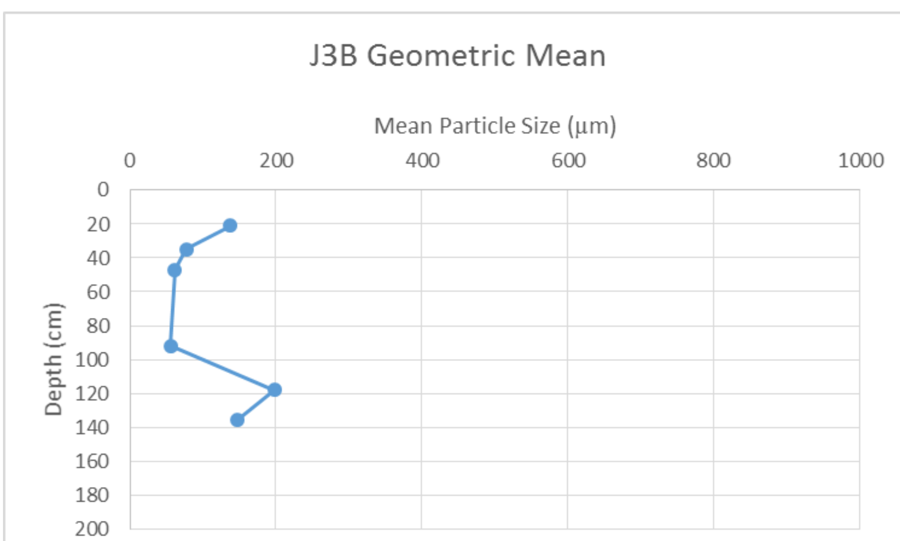

W4A Geometric Mean
Mean Particle Size (µm)
0
200
400
600
800
1000
Depth (cm)
0
20
40
60
80
100
120
140
160
180
200

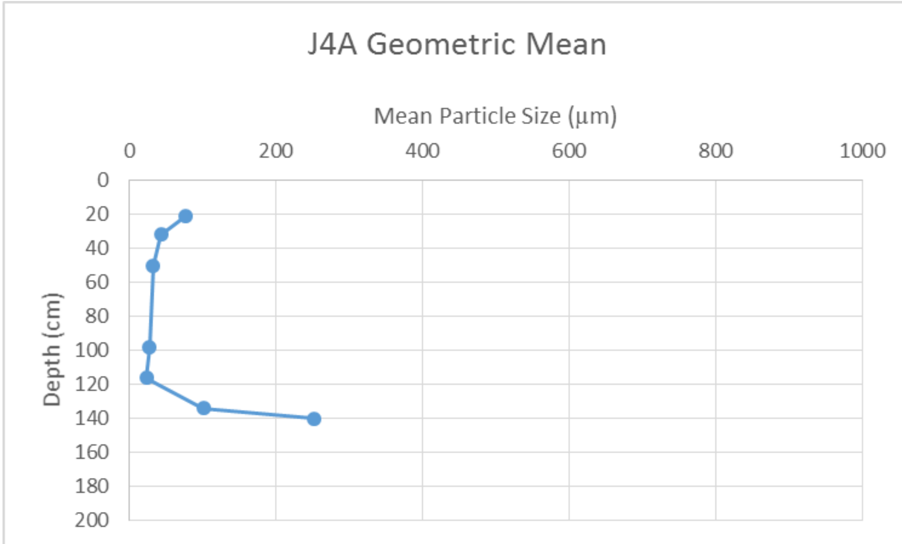

W5B Geometric Mean
Mean Particle Size (µm)
0
200
400
600
800
1000
Depth (cm)
0
20
40
60
80
100
120
140
160
180
200

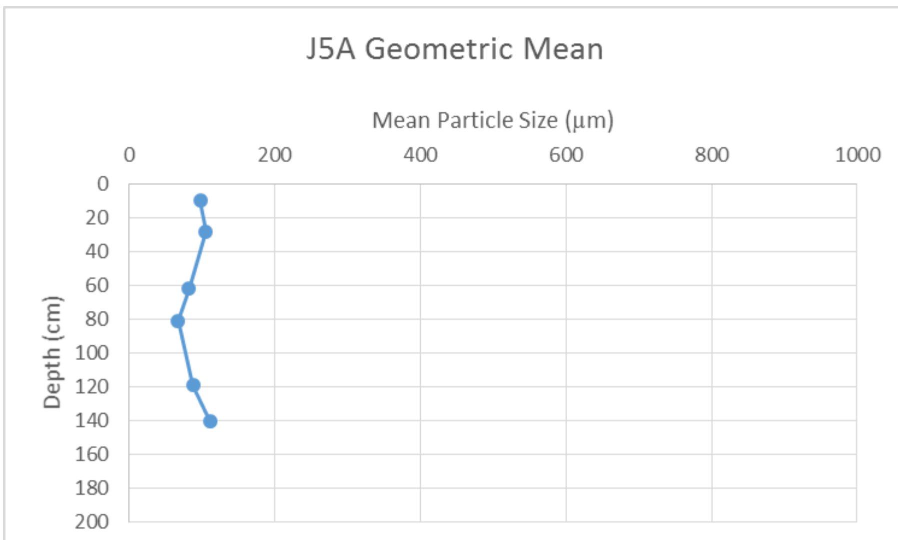

W6C Geometric Mean
Mean Particle Size (µm)
0
200
400
600
800
1000
Depth (cm)
0
20
40
60
80
100
120
140
160
180
200

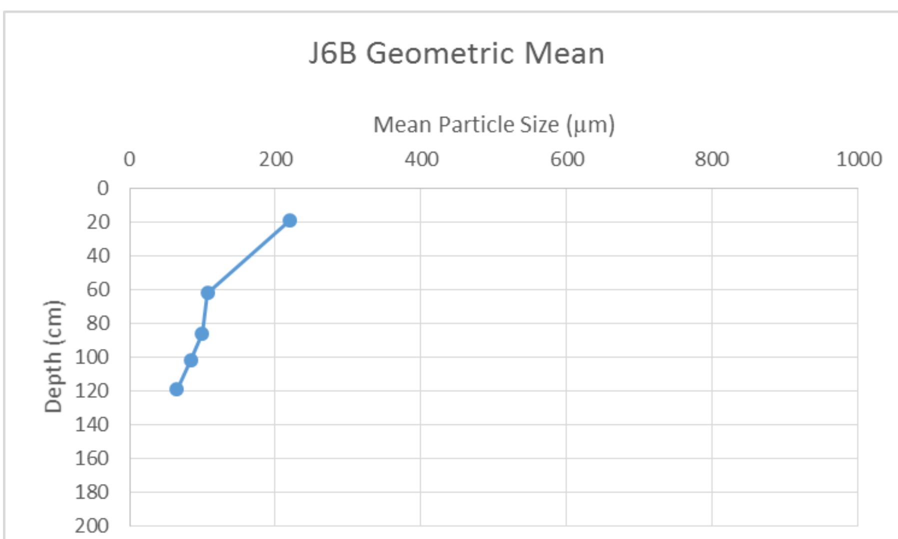

J1A Geometric Mean
Mean Particle Size (µm)
0
200
400
600
800
1000
Depth (cm)
0
20
40
60
80
100
120
140
160
180
200

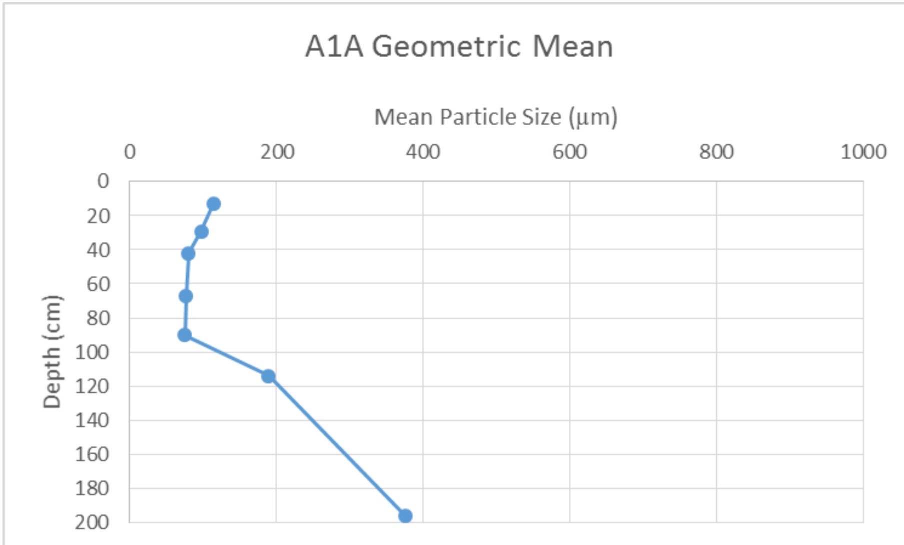

J2B Geometric Mean
Mean Particle Size (µm)
0
200
400
600
800
1000
Depth (cm)
0
20
40
60
80
100
120
140
160
180
200

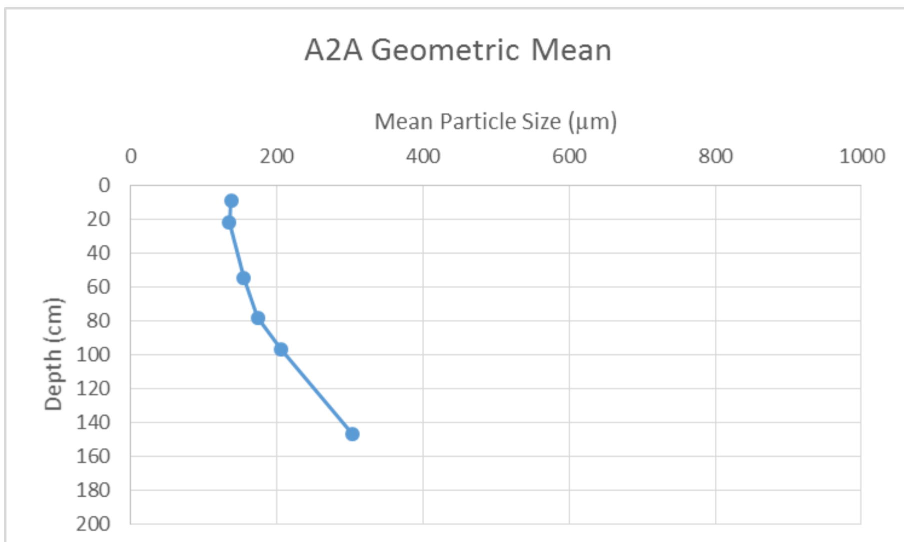

J3B Geometric Mean
Mean Particle Size (µm)
0
200
400
600
800
1000
Depth (cm)
0
20
40
60
80
100
120
140
160
180
200

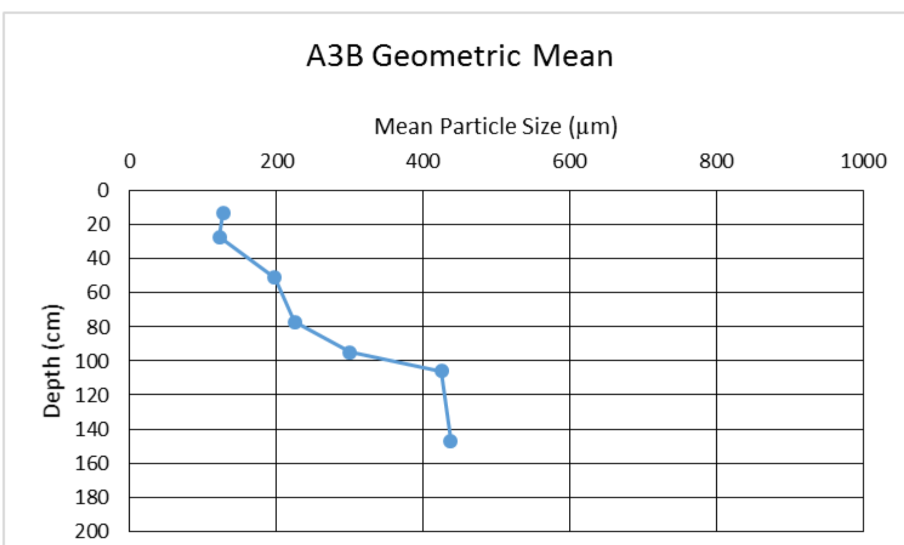

J4A Geometric Mean
Mean Particle Size (µm)
0
200
400
600
800
1000
Depth (cm)
0
20
40
60
80
100
120
140
160
180
200

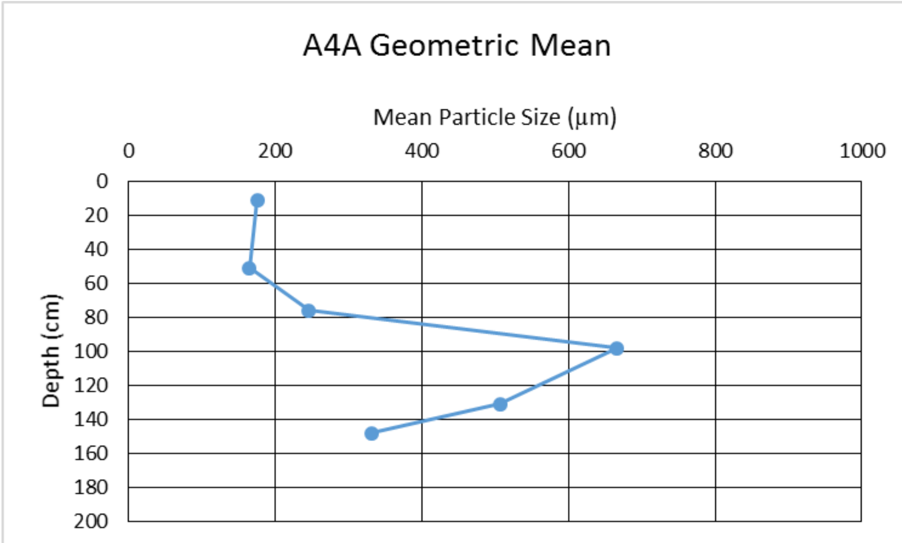

J5A Geometric Mean
Mean Particle Size (µm)
0
200
400
600
800
1000
Depth (cm)
0
20
40
60
80
100
120
140
160
180
200

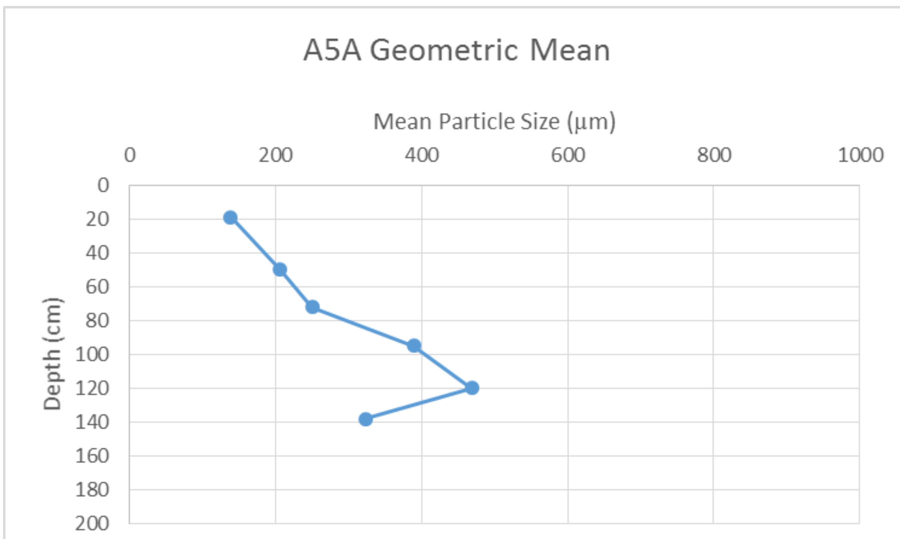

J6B Geometric Mean
Mean Particle Size (µm)
0
200
400
600
800
1000
Depth (cm)
0
20
40
60
80
100
120
140
160
180
200


A1A Geometric Mean
Mean Particle Size (µm)
0
200
400
600
800
1000
Depth (cm)
0
20
40
60
80
100
120
140
160
180
200


A2A Geometric Mean
Mean Particle Size (µm)
0
200
400
600
800
1000
Depth (cm)
0
20
40
60
80
100
120
140
160
180
200


A3B Geometric Mean
Mean Particle Size (µm)
0
200
400
600
800
1000
Depth (cm)
0
20
40
60
80
100
120
140
160
180
200


A4A Geometric Mean
Mean Particle Size (µm)
0
200
400
600
800
1000
0
20
40
60
80
100
120
140
160
180
200
Depth (cm)


A5A Geometric Mean
Mean Particle Size (µm)
0
200
400
600
800
1000
0
20
40
60
80
100
120
140
160
180
200
Depth (cm)

APPENDIX D

UTM COORDINATES FOR SOIL CORING SITES

		UTM Coordinates (15T)	
Location	**Site ID**	**Easting**	**Northing**
Hallett	H1	348227	4815222
Hallett	H2	348225	4815288
Hallett	H3	348288	4815454
Hallett	H4	348425	4814280
Hallett	H5	348188	4813884
Hallett	H6	348263	4813876
Hallett	H7	348413	4814118
Hallett	H8	348319	4815418
Wildin	W1	401385	4763006
Wildin	W2	401508	4762988
Wildin	W3	401247	4762904
Wildin	W4	401338	4762856
Wildin	W5	401416	4762749
Wildin	W6	401443	4762598
Jenkins	J1	422048	4654639
Jenkins	J2	421930	4654758
Jenkins	J3	421855	4654593
Jenkins	J4	421741	4654564
Jenkins	J5	421560	4654579
Jenkins	J6	421372	4654684
Avon Lake	A1	457905	4596911
Avon Lake	A2	457893	4596795
Avon Lake	A3	457757	4596720
Avon Lake	A4	457741	4596854
Avon Lake	A5	457741	4596976

APPENDIX E

DATA COMPILATION FOR NON-OUTWASH SOILS

Series	ID	Horizon	Horizon depth (cm)	Horizon thick. (cm)	Texture	% Sand	% Silt	% Clay	% Coarse fragments	Geometric mean (μm)	Fine earth fraction sand				
											% v. coarse	% coarse	% medium	% fine	% v. fine
Wiota	J1A-1	Ap	19	19	SiL	20.6	55.2	24.2	3.9	98	2.2	2.1	4.4	6.4	5.6
	J1A-2	A1	38	19	SiL	18.7	54.9	26.4	1.6	62	0.6	0.8	3.5	7.0	6.3
	J1A-3	A2	60	22	SiL	21.6	54.0	24.4	0.0	57	0.2	0.5	3.3	8.5	8.5
	J1A-4	AB	82	22	L	26.9	49.0	24.0	0.0	59	0.1	0.4	3.4	10.5	11.0
	J1A-5	Bt1	108	26	L	44.8	33.9	21.3	0.0	77	0.0	0.2	3.5	20.5	18.3
	J1A-6	Bt2	133	25	SiCL	13.0	49.2	37.7	0.0	36	0.1	0.2	1.1	5.4	5.8
	J1A-7	Bt3	147	14	CL	22.4	47.1	30.5	0.0	39	0.2	0.1	1.0	4.0	13.8
Wadena	J2B-1	Ap	16	16	SL	55.0	30.3	14.7	2.8	170	2.5	2.1	12.7	27.9	9.6
	J2B-2	A	34	18	SL	52.6	32.1	15.3	2.0	136	0.6	1.0	13.4	28.2	9.3
	J2B-3	Bw1	52	18	L	42.5	33.3	24.1	0.0	102	0.0	0.2	10.9	23.3	7.9
	J2B-4	Bw2	82	30	SCL	51.5	25.4	23.1	0.0	118	0.0	0.3	12.6	28.1	9.9
	J2B-5	C1	100	18	SL	78.8	8.3	12.9	0.0	165	0.0	0.4	17.2	43.1	17.7
	J2B-6	C2	141	41	LS	84.4	6.9	8.7	0.0	185	0.0	0.3	19.0	53.0	12.6

											Fine earth fraction sand				
Series	ID	Horizon	Horizon depth (cm)	Horizon thick. (cm)	Texture	% Sand	% Silt	% Clay	% Coarse fragments	Geometric mean (μm)	% v. coarse	% coarse	% medium	% fine	% v. fine
Moingona	J3B-1	Ap	21	21	L	38.0	47.2	14.8	2.6	137	3.3	1.6	7.3	14.3	10.4
	J3B-2	A	35	14	L	31.1	49.8	19.1	0.7	77	0.3	0.7	5.6	13.2	9.5
	J3B-3	BA	47	12	L	26.4	50.0	23.6	0.0	62	0.1	0.3	3.9	11.0	10.5
	J3B-4	Bt	92	45	CL	27.6	44.5	27.9	0.0	56	0.0	0.2	3.4	9.7	13.9
	J3B-5	2C1	118	26	LS	82.5	7.5	10.0	0.0	198	0.1	1.1	23.9	46.9	10.8
	J3B-6	2C2	136	18	SL	77.6	10.7	11.6	0.0	147	0.1	0.3	10.5	44.8	21.5
Sattre	J4A-1	Ap1	21	21	SiL	28.1	54.6	17.3	2.1	76	1.0	1.0	3.8	7.7	12.2
	J4A-2	Ap2	32	11	SiL	19.0	57.8	23.2	0.0	43	0.0	0.3	2.1	4.3	10.6
	J4A-3	BE	50	18	SiCL	12.4	60.0	27.6	0.0	33	0.0	0.1	0.7	2.9	8.7
	J4A-4	Bt1	98	48	SiCL	5.6	63.3	31.2	0.0	27	0.0	0.2	0.8	1.2	3.0
	J4A-5	Bt2	116	18	SiC	4.2	55.0	40.9	0.0	23	0.0	0.1	0.7	0.9	2.7
	J4A-6	2Bt3	134	18	SL	61.3	20.1	18.6	0.0	101	0.1	0.6	10.1	13.4	33.9
	J4A-7	2C	140	6	SL	76.1	11.4	12.5	0.1	253	0.0	2.0	56.2	9.1	8.4
Wadena	J5A-1	Ap1	10	10	L	44.9	36.9	18.2	2.2	98	0.9	1.3	4.7	16.6	19.8
	J5A-2	Ap2	28	18	L	48.1	35.0	16.9	2.6	105	1.2	1.5	4.2	17.8	21.8
	J5A-3	Bw1	62	34	SL	62.5	24.0	13.5	0.0	82	0.0	0.1	1.0	23.3	35.3
	J5A-4	Bw2	81	19	SL	52.8	28.4	18.8	0.0	67	0.0	0.1	0.6	16.8	31.6
	J5A-5	BC	119	38	SL	71.8	16.9	11.3	0.0	88	0.0	0.1	1.0	24.1	43.6
	J5A-6	C	140	21	LS	81.5	10.3	8.3	0.0	111	0.0	0.0	1.5	37.9	40.5
Sattre	J6B-1	Ap	19	19	SL	66.3	22.6	11.1	3.6	219	3.1	6.3	17.0	22.6	15.7
	J6B-2	BA	62	43	CL	37.2	35.2	27.7	0.5	107	1.1	2.8	7.4	11.4	13.1
	J6B-3	Bt1	86	24	CL	29.4	41.8	28.9	0.2	100	0.5	4.0	8.1	7.1	8.4
	J6B-4	Bt2	102	16	CL	21.3	45.2	33.5	0.6	84	1.2	2.3	5.4	4.9	7.5
	J6B-5	Bt3	119	17	SiCL	16.3	47.5	36.3	0.1	65	0.5	1.8	4.8	4.1	6.1

Series	ID	Horizon	Horizon depth (cm)	Horizon thick. (cm)	Texture	% Sand	% Silt	% Clay	% Coarse fragments	Geometric mean (µm)	Fine earth fraction sand % v. coarse	% coarse	% medium	% fine	% v. fine
Wiota	H3A-1	Ap	23	23	CL	20.7	47.2	32.2	0.2	70	0.6	1.6	4.3	7.0	7.1
	H3A-2	A	70	47	SiCL	14.3	51.1	34.6	0.1	49	0.3	0.9	2.5	4.4	6.0
	H3A-3	AB	89	19	SiCL	14.2	50.1	35.7	0.9	53	0.8	1.1	1.6	3.8	6.6
	H3A-4	Bt1	101	12	SiC	7.6	49.6	42.8	0.3	47	1.3	0.5	0.9	1.9	2.9
	H3A-5	Bt2	156	55	SiC	4.5	49.0	46.5	0.0	22	0.0	0.0	0.8	1.8	1.8
	H3A-6	2C	165	9	LS	82.4	5.7	12.0	9.2	240	2.6	1.1	27.1	44.5	6.8

Table continued

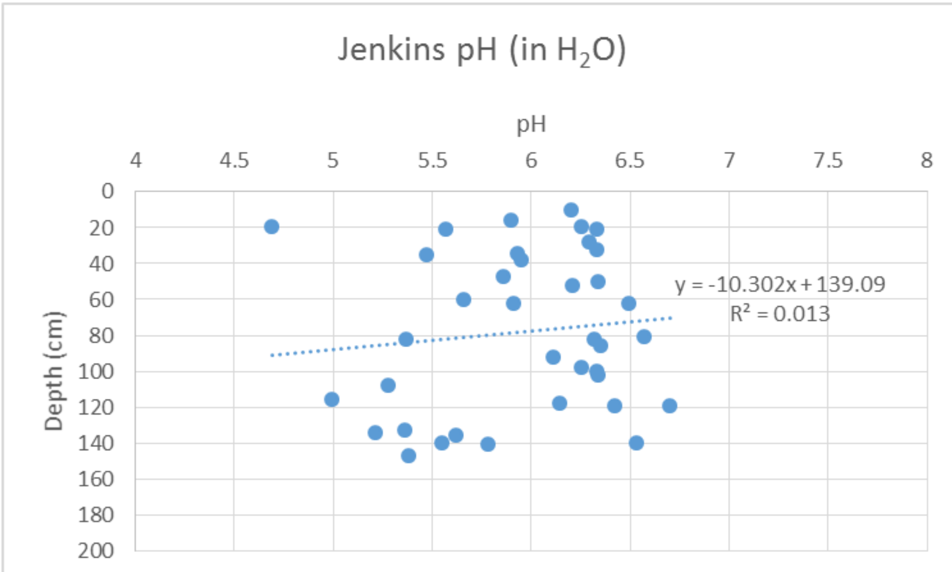
ID	B.D. (g/cm3)	pH H2O	pH 0.01M KCl	% Calcite	% Dolomite	% Total Carb.	% SOM	% SOC	% Air dry moisture
J1A-1	1.1	6.25	6.12	0.00	0.00	0.00	6.94	4.45	2.8
J1A-2	1.3	5.95	5.77	0.00	0.00	0.00	5.12	3.20	2.7
J1A-3	1.4	5.66	5.37	0.00	0.00	0.00	3.23	1.92	2.3
J1A-4	1.5	5.37	5.06	0.00	0.00	0.00	2.45	1.38	2.1
J1A-5	1.6	5.28	5.07	0.00	0.00	0.00	1.39	0.66	1.9
J1A-6	1.5	5.36	5.14	0.00	0.00	0.00	1.95	1.04	3.7
J1A-7	1.5	5.38	5.18	0.00	0.00	0.00	1.53	0.76	3.0
J2B-1	1.3	5.90	5.94	0.00	0.00	0.00	3.26	1.94	1.2
J2B-2	1.7	5.93	5.94	0.00	0.00	0.00	2.43	1.37	1.5
J2B-3	1.5	6.21	5.98	0.00	0.00	0.00	1.97	1.06	2.2
J2B-4	1.5	6.32	6.02	0.00	0.00	0.00	1.45	0.70	2.0
J2B-5	1.5	6.33	6.03	0.00	0.00	0.00	0.92	0.34	1.0
J2B-6	1.5	5.78	5.43	0.00	0.00	0.00	0.56	0.09	0.9

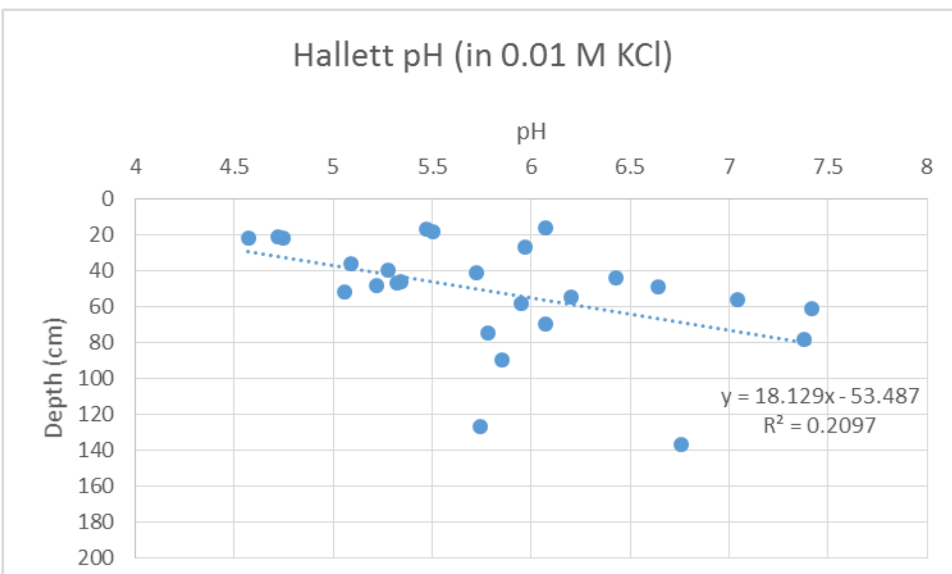
ID	B.D. (g/cm3)	pH H2O	pH 0.01M KCl	% Calcite	% Dolomite	% Total Carb.	% SOM	% SOC	% Air dry moisture
J3B-1	1.3	5.57	5.58	0.00	0.00	0.00	3.66	2.21	1.4
J3B-2	1.6	5.47	5.33	0.00	0.00	0.00	2.37	1.33	1.6
J3B-3	1.4	5.86	5.67	0.00	0.00	0.00	1.96	1.05	1.8
J3B-4	1.5	6.11	5.77	0.00	0.00	0.00	1.74	0.90	3.1
J3B-5	1.8	6.14	5.80	0.00	0.00	0.00	0.67	0.17	0.7
J3B-6	1.9	5.62	5.41	0.00	0.00	0.00	0.65	0.16	1.3
J4A-1	1.4	6.33	6.22	0.00	0.00	0.00	3.33	1.98	1.7
J4A-2	1.6	6.33	6.08	0.00	0.00	0.00	2.21	1.22	2.1
J4A-3	1.5	6.34	6.02	0.00	0.00	0.00	1.85	0.98	3.0
J4A-4	1.4	6.25	5.91	0.00	0.00	0.00	1.84	0.97	3.7
J4A-5	1.5	4.99	4.66	0.00	0.00	0.00	1.48	0.72	4.5
J4A-6	1.6	5.21	4.89	0.00	0.00	0.00	0.84	0.29	1.8
J4A-7	1.8	5.55	5.21	0.00	0.00	0.00	0.48	0.04	0.6
J5A-1	1.1	6.20	6.12	0.00	0.00	0.00	4.09	2.51	1.4
J5A-2	1.4	6.29	6.19	0.00	0.00	0.00	4.00	2.44	1.8
J5A-3	1.6	6.49	6.16	0.00	0.00	0.00	0.95	0.36	1.1
J5A-4	1.5	6.57	6.19	0.00	0.00	0.00	1.20	0.53	2.0
J5A-5	1.4	6.70	6.30	0.00	0.00	0.00	0.80	0.26	1.3
J5A-6	1.8	6.53	6.25	0.00	0.00	0.00	0.54	0.08	0.9
J6B-1	1.7	4.69	4.76	0.00	0.00	0.00	2.01	1.08	0.9
J6B-2	1.7	5.91	5.66	0.00	0.00	0.00	1.62	0.82	2.8
J6B-3	1.6	6.35	6.04	0.00	0.00	0.00	1.81	0.95	2.6
J6B-4	1.7	6.34	6.01	0.00	0.00	0.00	1.50	0.74	3.4
J6B-5	1.7	6.42	6.07	0.00	0.00	0.00	1.35	0.64	4.1

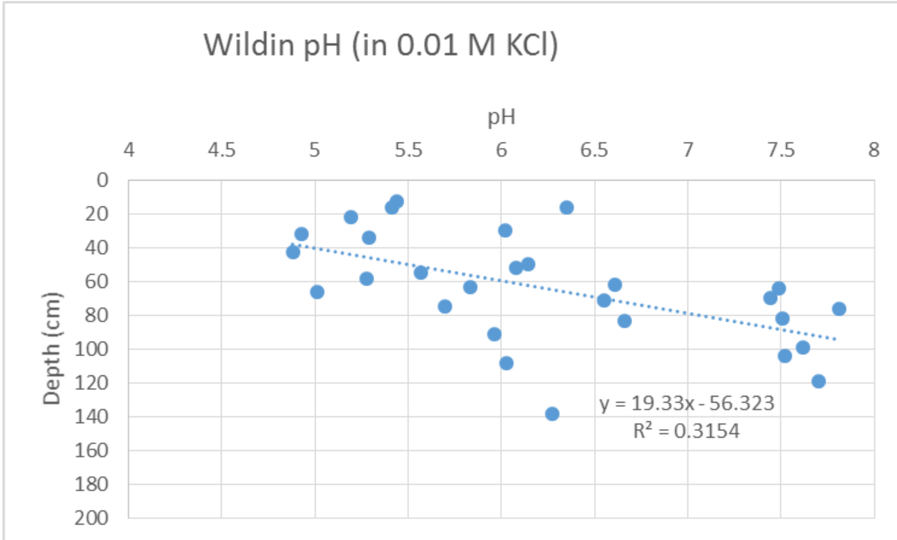
ID	B.D. (g/cm3)	pH H2O	pH 0.01M KCl	% Calcite	% Dolomite	% Total Carb.	% SOM	% SOC	% Air dry moisture
H3A-1	1.2	5.38	5.38	0.00	0.00	0.00	6.26	3.99	3.1
H3A-2	1.3	5.44	5.28	0.00	0.00	0.00	4.44	2.74	3.2
H3A-3	1.3	5.74	5.43	0.00	0.00	0.00	2.77	1.60	3.2
H3A-4	1.3	5.74	5.44	0.00	0.00	0.00	2.61	1.50	4.2
H3A-5	1.4	6.04	5.67	0.00	0.00	0.00	1.93	1.03	4.8
H3A-6	1.4	5.83	5.62	0.00	0.00	0.00	0.65	0.16	1.1

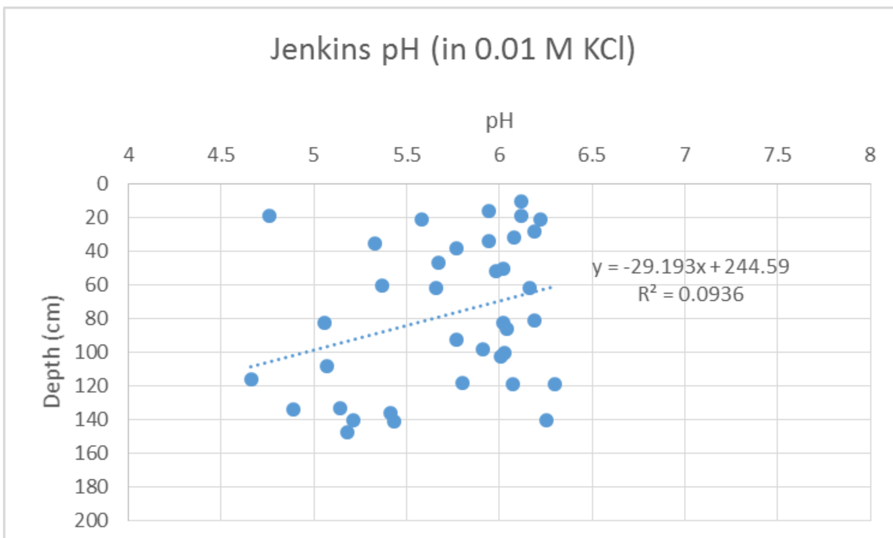
APPENDIX F

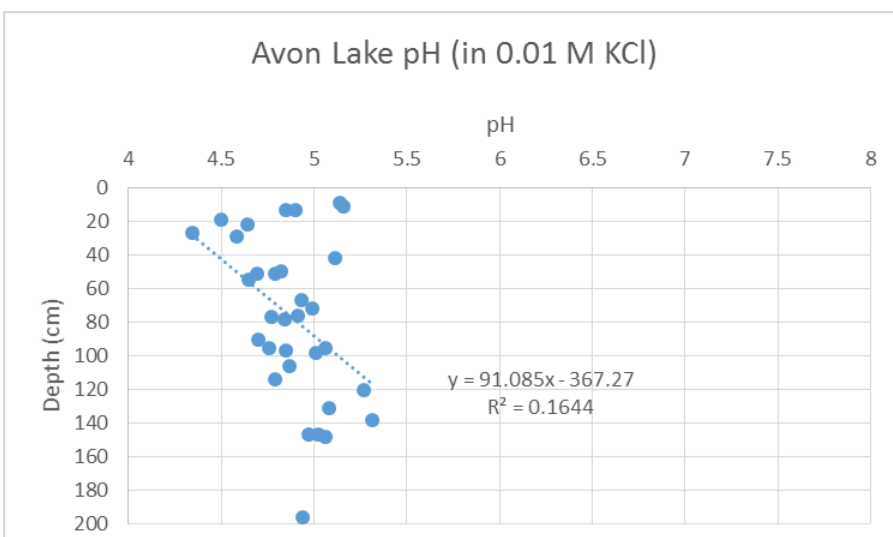
ADDITIONAL PLOTS OF SOIL PH






Wildin pH (in 0.01 M KCl)
pH
4
4.5
5
5.5
6
6.5
7
7.5
8
Depth (cm)
0
20
40
60
80
100
120
140
160
180
200
y = 19.33x - 56.323
R² = 0.3154


Jenkins pH (in 0.01 M KCl)
pH
4
4.5
5
5.5
6
6.5
7
7.5
8
Depth (cm)
0
20
40
60
80
100
120
140
160
180
200
y = -29.193x + 244.59
R² = 0.0936


Avon Lake pH (in 0.01 M KCl)
pH
4
4.5
5
5.5
6
6.5
7
7.5
8
Depth (cm)
0
20
40
60
80
100
120
140
160
180
200
y = 91.085x - 367.27
R² = 0.1644